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BY

EDWARD L. NICHOLS

ERNEST MERRITT, and FREDERICK BEDELL

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APRIL, 1910

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THE EFFECT OF CHANGES IN THE PRESSURE AND TEMPERATURE OF GASES UPON THE MOBILITY OF THE NEGATIVE IONS PRODUCED BY ULTRA-VIOLET LIGHT.

By Alois F. Kovarik.

§ 1. Introduction.

THE experiments to be described in this paper had for their object the investigation of the changes produced in the ionic velocity by variations in the pressure and temperature of the gas. The ions used were the negative ones which are produced by ultra-violet light falling upon a negatively charged metal surface.

It is known that at very low pressures these ions are corpuscular in size, and if, when the gas is at atmospheric pressure, they consist of clusters of molecules about charged nuclei, as is generally believed, then evidently as the pressure is reduced the cluster must eventually fail to form. A study of the ionic velocity at different pressures should reveal whether a change in the size of the ion actually takes place, and if it does, whether the cluster gets smaller gradually as the pressure is diminished or whether the change in size is more or less abrupt.

Again, the size of the ion may depend upon the temperature, and a determination of the ionic velocity at different temperatures should throw some light upon this point.

In the present investigation the ionic velocity was determined in air and carbon dioxid for pressures between 8.8 mm. and 760 mm. of mercury, and in air at atmospheric pressure for temperatures between 84.5 and 698 degrees absolute.

Some results[1] on the effects of pressure and temperature upon the ionic velocity had been published already when these experiments were begun two years ago, and other papers[2] have appeared since, but the present results extend the ranges of the variations heretofore published and are not in complete agreement with some of the previous observations.

The subject matter will be treated under the following headings:

§ 2. Method.
§ 3. Pressure apparatus.
§ 4. Precautions aad corrections observed in the experiments.
§ 5. First pressure experiments in dry air and in dry carbon dioxid.
§ 6. Final experiments in dry air and in dry carbon dioxid.
§ 7. Temperature experiments.
§ 8. Summary and conclusion.

§ 2. METHOD.

The method used for determining the mobility of the ions is a modification of that used by Rutherford.[3] One of two parallel plates is illuminated by the ultra-violet light and charged with an alternating potential, and the electrical charge carried by the ions to the second plate is observed for different values of the alternating potential.

Let t be the half-period of the alternating field, u the mobility of the ions (*i. e.*, their velocity in a field of one volt per centimeter), P the potential difference between the plates, and d their distance apart. Then the space the ions will travel from the illuminated plate in the time t is

$$s = \frac{P}{d} ut.$$

While P is so small that s is less than d, no ions starting from the illuminated plate can get to the second plate before their motion is reversed by the reversal of the field. It is only after the potential

[1] Rutherford, E., Proc. Camb. Phil. Soc., Vol. 9. p. 401, 1898. Langevin, P., Ann. de Chimie et de Physique, 28, p. 289, 1903. Phillips, P., Proc. Roy. Soc., A, p. 167, 1906.

[2] Blanc, A., J. de Phys. (4), 7, p. 825, 1908. Wellisch, E. M., Proc. Camb. Phil. Soc., Vol. 15, p. 1, 1908; Phil. Trans., A, Vol. 209, pp. 249–279, 1909.

[3] Loc. cit.

has reached some value P_0, which makes s equal to d, that some of the ions which were produced at the beginning of an alternation can get across to the second plate before the field is reversed. As the potential is increased further, the quantity of electricity reaching the second plate should for a time increase regularly with the increase of potential, and finally when practically all of the ions produced by the light are carried to the second plate, any further increase in the potential should not alter the charge received.

If, therefore, values proportional to the charge received are plotted against the corresponding values of P, the curve should start as a straight line from the point P_0 on the axis of P and finally become horizontal. The experimental curve does not actually start as a straight line from P_0, for reasons given later, but it has a well defined straight portion which produced intersects the axis of potentials at P_0.

Knowing the value of P_0, the rate of alternation and the distance between the plates, the value of the mobility can be obtained from the relation

$$u = \frac{d^2}{P_0 t} = \frac{2nd^2}{P_0},$$

where n represents the number of alternations of the field per second.

§ 3. Pressure Apparatus.

The vessel in which the ionic velocity was measured at different pressures (see Fig. 1.) was made of a brass tube 10 cm. long and 10 cm. in diameter. The rear of the vessel was permanently closed by a heavy brass plate P having in its center an ebonite plug E forced into a brass collar. A brass rod R, holding the illuminated plate and strong enough not to bend appreciably when in a horizontal position, was screwed into the ebonite plug and had a wire leading to the source of potential. The zinc plate Z exposed to the light was 8 cm. in diameter, turned to a true plane and polished with a buffer and vienna lime. It had a ball and socket arrangement which permitted its plane to be adjusted by means of three srcews whose points rested against its rear face and passed through another plate rigidly fixed to a strong brass tube T which fitted over the rod R

to which it was firmly screwed when the zinc plate was set for any required distance from the opposite parallel plate. The fore part of the vessel was closed by a removable heavy brass plate having a circular groove cut in it to fit the cylinder. This cover could be brought tight against the cylinder by means of thumb screws *SS* fitted to four rods passing through the cover and extending to the rear plate on the outside of the vessel. The second of the parallel plates was a gauze *G* placed flush with the inner surface of the cover and had a ring of air one millimeter wide around it. The cover thus served as a guard ring. The gauze was made of No. 40 brass wire, two wires to a millimeter running in one direction only. It was held in position by a screw passing through an ebonite plug which was forced into a brass collar in the cover. A wire soldered to the screw led to the electroscope. A window 3.6 cm. in diameter was cut centrally with respect to the parallel plates and was closed by a quartz plate *Q* held in position by paraffin. The groove and all points of juncture were paraffined.

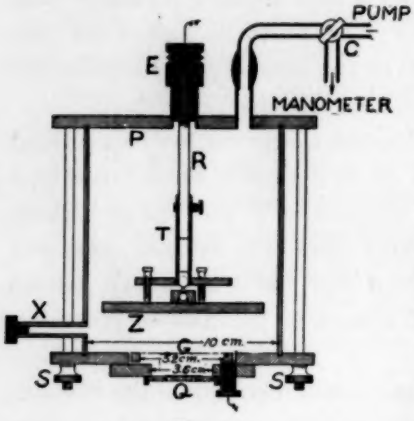

Fig 1.

A three-way stop-cock *C* was sealed with wax into the rear plate. One of its arms led to the manometers and another to the pump and source of supply of gases. An exit tube *X* was also provided in the fore part of the vessel. A diagram of the various connections is given in Fig. 2.

The mercury manometers used were the open air manometer *A* and the baromanometer *B*, the latter being used for pressures less than 150 millimeters. Readings were made by means of a cathetometer.

A C. T. R. Wilson's inclined electroscope *W* was used for the measurement of electric charges. An electroscope was chosen in preference to a quadrant electrometer because the inappreciable

inertia of the leaf permits quick repetition of observations. The plate of the electroscope was connected to a series of 91 small lead accumulators D, the other pole of the series being connected to a slide movable over a high resistance R through which a current was continually flowing from a large chloride accumulator F, the positive pole of which was earthed. In this manner the zero could

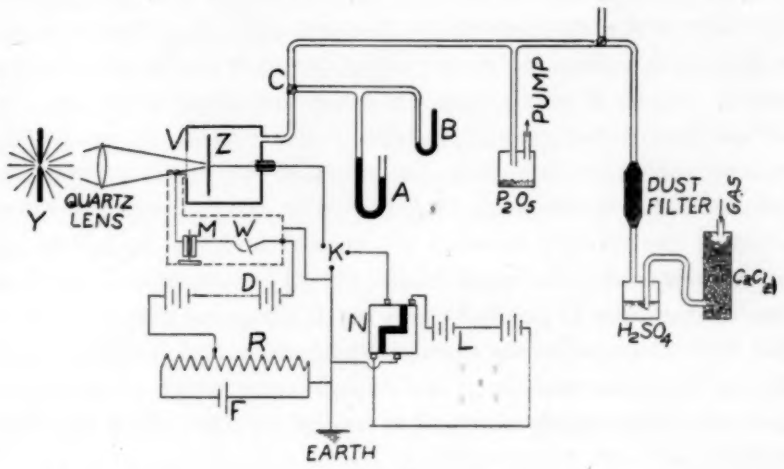

Fig. 2.

be easily kept fixed if for any reason the potential of the plate changed. The leaf was connected through a McLennan key M to the gauze of the testing vessel V. The sensitiveness of the electroscope was 17.5 divisions in the eye-piece for one volt, but only 5 divisions, corresponding to 0.35 volt, were used, as the sensitiveness over this distance was found convenient and also uniform.

The source of potential was a series of small lead accumulators L. The alternation of the field was brought about by a secohmmeter N. A triple key K was placed between the secohmmeter and the zinc plate, the third connection being to earth.

In the first experiments, the source of light Y was a spark between two zinc electrodes connected to the terminals of an induction coil. In the course of the investigation it was found that when synchronism existed between the alternation of the field and the intermittence of the light, the observations could not be depended upon. An arc between iron electrodes was consequently substituted

for the spark. The light from the arc was generally not as steady as from the spark, but by giving it sufficient attention it could be kept fairly constant.

§ 4. PRECAUTIONS AND CORRECTIONS OBSERVED IN THE EXPERIMENTS.

1. A small portion of the light incident on the zinc plate strikes the walls of the vessel which are charged alternately positively and negatively by induction. Some of the ions thus produced reach the gauze. Again a certain number of the ions produced at the zinc diffuse toward the gauze. In both of these cases, the gauze will receive a charge even when the potential difference between the parallel plates is less than P_0. Evidently, the experimental curve showing the relation between the current and the potentials will begin with values of P smaller than P_0. The quantity of electricity due to these ions is generally very small compared with that due to the ions coming directly from the zinc plate and for this reason the straight line portion of the experimental curve obtained with potentials immediately above P_0 is readily separated from the curve below P_0.

It was also observed that when the zinc plate became coated with a film of oxide or of moisture, the gold leaf showed a charge opposite in sign to that which it received when the zinc plate acted photo-electrically. This is due to the production of negative ions at the surface of the gauze by the light reflected from the zinc plate and also by that directly incident upon it, thus charging the gauze to a positive potential. When the zinc is polished, the effect of the gauze in sending out ions toward the zinc on alternate intervals is to decrease the effect of the zinc by a certain per cent. The effect of this in the curve is to decrease each ordinate by a fixed per cent. of itself, which alters the slope of the straight line portion of the curve without altering the intersection with the axis of potentials, *i. e.*, P_0 is unaffected by this phenomenon. This point was carefully tested by coating the gauze and the interior of the vessel with lamp black.

2. It was observed that with a slow rate of alternation of the field — *i. e.*, when the time required by the ions to pass between the plates was large — the velocity obtained was smaller than with a

high rate of alternation. At atmospheric pressure the difference between the values obtained is quite small but at low pressures it is very pronounced. This behavior is probably due to the diffusion of the ions to the sides.[1] It is however possible that if the ions are complex, they require a time comparable to that used in the experiments to grow to the final size, in which case also the value of the velocity with the long time of passage between the plates should be smaller than with the short time. When the values of the velocity were plotted against the time required for the ions to cross the field, the distribution was found to be linear and by producing the straight line thus obtained until it intersected the ordinate at the time $T = 0$, a value of the velocity was found which in each case was used as the desired velocity. It was therefore necessary to obtain values for the mobility using different rates of alternation and hence different values of T.

3. The use of a guard ring, small distances between the plates and a large zinc plate insured a uniform field. The ions were made to move, in most of the experiments, in the central portion, by having only a small central area of the zinc illuminated. This was brought about by a quartz lens in front of the apparatus.

No tests were made on the non-uniformity of the distribution of potential between the plates.[2] Experiments were, however, performed with different intensities of light but the value of the velocity was found to be unaffected by such changes. No correction was, therefore, made in the calculation.

4. The source of light is, of course, subject to changes in intensity but these changes were greatly obviated by proper attention. However, the readings were taken in such a manner as to minimize any errors arising from any changes in the intensity occurring during an experiment. Sometimes readings were taken with increasing potentials and then decreasing, the mean for any potential being used as the final value. Generally, however, some high potential was chosen and readings taken for this potential were considered as control readings. The control readings preceded and followed

[1] See also J. Zeleny, Phil. Trans., A, 195, p. 193, 1900.

[2] Zeleny, J., Phil. Mag., 46, p. 120, 1898. Childs, Wied. Ann., 65, p. 152, 1898. Schweidler, quoted by Prof. Thomson, Cond. of Elect., p. 260. Buisson, H., C. R., CXXVII., p. 224, 1898.

each individual reading for any potential. Then by interpolation all the readings were reduced to some uniform value of the control reading. In this manner any gradual changes in the intensity of the light during any one reading could be readily corrected. This plan of taking readings also corrects for the photo-electric fatigue when this is small; and it was found to be small, after the plate had been exposed to the light for some time. Tests on this point were made in air and in carbon dioxid, at atmospheric pressure and at low pressure.

5. On account of electrostatic induction the potential difference between the parallel plates is less than the potential of the zinc plate. The amount of the diminution can be readily found experimentally. This it shown by a specific example. The gauze at zero potential was insulated from the earth. The zinc plate then received a charge from 8 cells equivalent to 16.6 volts, and the leaf of the electroscope became deflected 8.8 divisions equivalent to 0.558 volt. The induction was, therefore, $0.558/16.6 = 3.37$ per cent. Using 22 cells $= 45.6$ volts, the deflection was 32 divisions $= 1.55$ volts, and the induction was $1.55/45.6 = 3.4$ per cent. Consequently, the value of P_0 obtained from the curve had to be diminished by 3.4 per cent., the distance between the plates in this case being 19.34 mm.

It is evident that on account of this induction the leaf will vibrate with the alternation of the field. The amount of this vibration depends on the induction, rate of alternation and the inertia of the leaf. In the present investigation it was found that for the potentials and the rate of alternation used, the vibration of the leaf could hardly be noticed. Exceptions noted are the ones with a very low rate of alternation and when the plates were very close together; but even in these cases, readings were easily taken as the vibration of the leaf did not exceed one half of a scale division. In these cases the mean position of the leaf had to be estimated.

6. The method used demands an equality of time for the opposite directions of the field. This depends on the secohmmeter itself and on the uniformity in the rate of rotation. If the brushes were not placed correctly or if they formed a poor contact with the segments, the leaf of the electroscope showed a "kick" to one side at the

moment when the zinc received the alternating charge. The "kick" is due to unequal induction. It was also noticed at times that the contact of the brushes with the segments produced a difference of potential which was also registered by a "kick" of the leaf. The former was remedied by careful adjustment of the brushes and the latter by cleaning the brushes and the segments, and rubbing both with paraffin oil,[1] carefully removing all excess.

It is here supposed that the field was fully established as soon as the brush came in contact with the segment of the secohmmeter. A water resistance always kept between the brush and the zinc plate was taken out and no difference was observed in the values of the mobility. Presumably then, the field establishes itself practically instantly through the resistance.

The alternating potential through the brushes was taken on a static voltmeter on different occasions and was found to correspond to the reading from a current voltmeter applied directly to the cells.

7. When there is an excess of ions of one kind in a gas, a force is exerted on the gas in these regions, which will produce a motion of the gas when the ions are in motion. A current of gas of this kind has been observed by Zeleny.[2] The motion of the gas is, however, very small in comparison with the velocity of the ions and the correction for it may be left out of account.

Convection currents due to difference of temperature in various parts of the field undoubtedly existed in a few of the temperature experiments. These will be noted in their proper place.

8. The reliability of the method used was tested by varying the distance between the plates, by varying the intensity of the incident light, and by changing the apparatus itself. In view of the fact that the values of the mobility of the ions in air at atmospheric pressure were all concordant under these various changes, it is believed that the method used is accurate.

9. In the experiments with dry gases the air was slowly passed into the exhausted vessel through a series of purifying and drying agents arranged as follows: potassium permanganate with dilute sulphuric acid, concentrated potassium hydroxid, calcium chloride,

[1] Allen, H. N., The Electrician (London), Vol. XXXIX., p. 379, 1897.
[2] Zeleny, J., Proc. Camb. Phil. Soc., X., p. 14, 1898.

concentrated sulphuric acid, and cotton; the carbon dioxid passed through the same series with the hydroxid omitted. The vessel was refilled with the gas 5 to 10 times before readings were taken at any pressure.

10. It hardly seems necessary to remark that due precautions were taken to carefully screen those portions of the apparatus requiring shielding from outside electrostatic disturbances.

§ 5. First Pressure Experiments.

Dry Air. — In the first experiments a spark was used as the source of light, the intensity of which varied very little. Only one set of readings was taken to obtain the value of the mobility. A set illustrating the readings and the calculation is given below.

Table I.

Pressure = Barometric reading = 734.0 mm.
Temperature = Room temperature = 24°.0 C.
5,000 alternations of the field in 139.0 sec. (beginning),
139.2 sec. (end),
139.1 sec. (mean),
or 35.95 alternations per second.
100 cells = 215.8 volts.
Distance between the parallel plates = 19.34 mm.

Potential of the Plate.	Time to Deflect Leaf 25th to 30th Division.		Reciprocal of the Time × 10^4.
60 cells	485.0	485.0 sec.	21
70	90.0		
	90.0	90.0	111
80	44.2		
	42.8		
	45.0	44.0	227
90	29.4		
	31.6		
	30.8	30.6	327
100	24.0		
	24.0		
	24.0	24.0	417
95	27.0		
	27.0		
	27.0	27.0	370
85	36.2		
	37.2	36.7	272
75	60.4		
	60.4	64.0	165
65	166.2	166.2	60

The reciprocal of the time is plotted against the potential in Fig. 3. The straight line portion of the curve intersects the axis of the

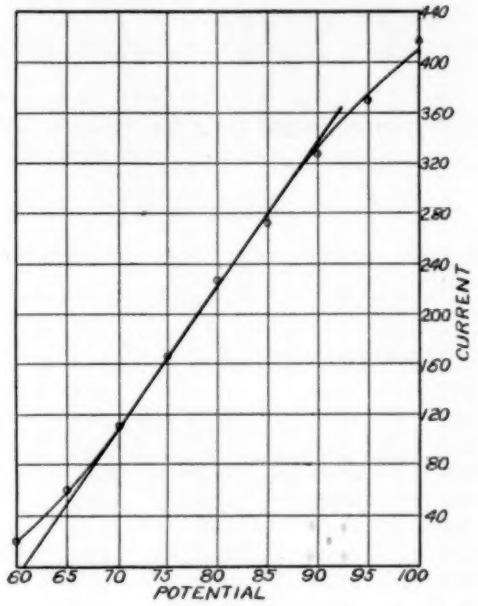

Fig. 3.

potentials at $P_0 = 60.7$ cells $= 131.0$ volts. The correction for the induction, as explained in § 4, 5, is 3.4 per cent. when $d = 19.34$ mm. and is, therefore, 4.5 volts. Hence,

$$P_0 = 131.0 - 4.5 = 126.5 \text{ volts.}$$

Substituting in the equation

$$u = \frac{2nd^2}{P_0},$$

we get

$$u = \frac{2 \times 35.95 \times 1.934 \times 1.934}{126.5}$$

$$= 2.13 \text{ cm. per sec. per volt per centimeter.}$$

The mobility will in each case be reduced to what it would be at a pressure of 760 mm., on the supposition that the mobilities at two pressures are inversely proportional to the pressures. The

mobility at 760 mm. pressure thus obtained will be designated by v. In the above example

$$v = \frac{u \times p}{760} = \frac{2.13 \times 734}{760} = 2.06 \text{ cm. per sec.}$$

Table II. gives the collected data for various pressures for dry air when $d = 19.25$ mm.

TABLE II.

Dry Air. Light from Spark Used. $d = 19.25$ *mm.*

p	t	T	n	P_0	u	v
746.0	20.0° C.	0.0129	38.7	133.4	2.15	2.11
743.4	19.0	.0100	49.5	180.4	2.03	1.98
735.0	20.0	.0078	64.0	224.0	2.12	2.05
736.0	20.0	.0125	40.2	143.5	2.06	2.00
734.0	24.0	.0139	35.95	123.7	2.16	2.08
510.5	20.0	.0080	62.5	146.6	3.16	2.12
408.1	19.0	.0080	62.0	121.3	3.78	2.03
268.5	20.0	.0079	63.5	78.4	6.00	2.12
207.9	20.0	.0083	60.6	61.0	7.35	2.01
180.4	24.0	.0079	63.7	48.3	9.75	2.31
169.3	19.0	.0081	61.9	45.0	10.4	2.32
166.0	25.0	.0079	63.5	45.6	10.3	2.25
140.2	20.0	.0079	62.8	36.3	12.8	2.36
90.3	20.0	.0084	59.3	20.34	21.6	2.57
64.0	20.0	.0104	48.0	10.88	32.7	2.76
53.9	21.0	.0080	62.3	9.64	48.0	3.40
36.0	19.5	.0079	63.5	4.59	102.4	4.85
27.7	21.0	.0080	62.3	3.47	133.0	4.84
11.4	20.0	.0079	63.3	1.16	404.0	6.07

The results of this table are shown graphically in Fig. 4. The curve shows that v is independent of p between the pressures 760 mm. and about 200 mm. At 200 mm. the curve rises somewhat, and at 100 mm. it passes through a pronounced bend. This rather sudden change in the mobility v indicates that near this pressure there is a rapid change in the mass of the ion, *i. e.*, the number of molecules which are supposed to be gathered about a central charge to form the ion rapidly diminishes on the average ion as the pressure is reduced below 100 mm.

Carbon Dioxid. — Readings similar to those for air were also taken for carbon dioxid. A set of these is given in Table III.

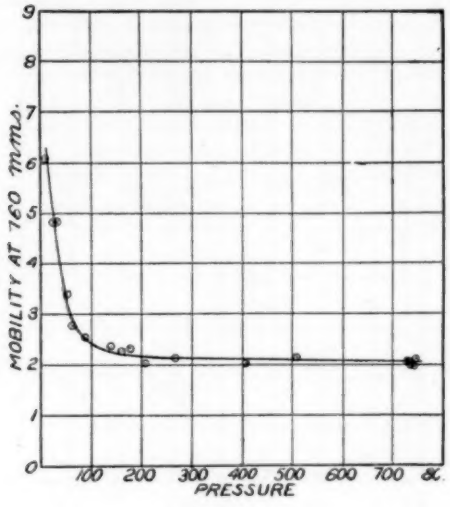

Fig. 4.

TABLE III.

Dry Carbon Dioxid. Light from Spark Used. $d = 19.25$ mm.

p	t	n	P_0	u	v
739.0	20.0	18.3	148.2	0.91	0.88
755.0	21.0	19.0	149.0	0.94	0.93
755.0	20.0	19.0	144.0	0.98	0.97
754.0	20.0	23.2	188.0	0.91	0.90
748.0	20.0	18.8	144.0	0.97	0.95
748.0	21.0	32.3	253.6	0.95	0.93
447.6	21.0	23.4	121.2	1.43	0.84
402.0	20.0	49.1	177.0	2.05	1.09
323.0	21.0	35.2	115.6	2.26	0.96
299.7	20.0	49.0	128.6	2.82	1.11
266.6	22.0	47.9	132.7	2.67	0.94
187.0	21.0	35.3	53.4	4.90	1.21
150.0	22.0	47.8	54.8	6.45	1.27
118.0	20.0	61.7	50.8	9.00	1.40
102.1	22.0	47.7	32.4	10.9	1.46
77.1	19.0	47.7	22.5	20.7	2.10
62.5	22.0	62.9	11.92	29.6	2.43
58.2	20.0	63.0	12.55	37.2	2.85
38.2	20.0	62.9	4.06	114.2	5.75
25.4	22.0	47.7	1.34	264.0	8.80

The values of v are plotted against p in Fig. 5. It will be noticed that here also there is a sudden change in the mobility v.

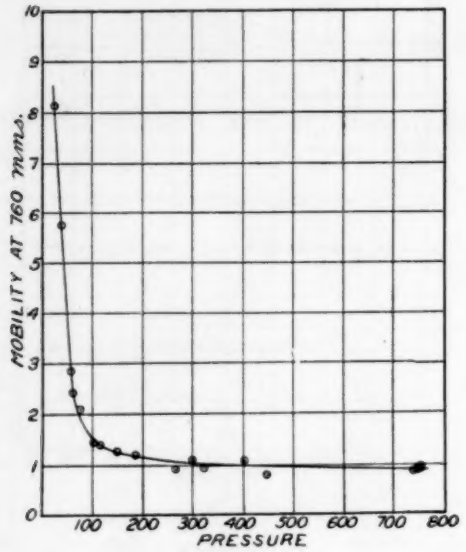

Fig. 5.

§ 6. FINAL PRESSURE EXPERIMENTS.

Dry Air. — In the final experiments all the precautions noted in § 4 were carefully observed. An arc between iron electrodes was used as the source of light in all of these experiments. The rate of alternation of the field was changed a sufficient number of times in each pressure experiment to permit the determination of the value of the mobility at $T = 0$, vide § 4, 2. An illustration of the general method of taking the readings with the arc as the source of light is given in Table IV(a).

The readings in Table IV(a) were next reduced and corrected for the changes in the intensity of the arc, vide § 4, 4. These results are tabulated in Table IV(b), 2,400 being taken as the current corresponding to the highest potential, namely 15 cells.

The curve showing the relation between the potential and the current is given in Fig. 6. The straight line portion of the curve produced intersects the axis of the potentials at 8.68 cells. The correction for induction is 3.4 per cent. The value of P_0 is therefore 8.38 cells or 17.27 volts.

TABLE IV(*a*).

Dry Air. Fe Arc Light. d = 19.34 *mm.*

Baromanometer reading = 97.8 mm.
20 cells = 41.2 volts. Temperature = 24°.0 C.
5000 alternations of the field in 104.4 sec. (beginning),
104.4 sec. (end),
104.4 sec. (mean),
or n = 47.8 per second.

Potential of the Plate.	Time to Deflect Leaf 25th to 30th Division.		Reciprocal of the Time ×10⁴.	Potential of the Plate.	Time to Deflect Leaf 25th to 30th Division.		Reciprocal of the Time ×10⁴.
15 cells	4.4			11	8.8		
	4.6				9.2		
	4.6				9.4		
	4.6				10.0	9.35	1,070
	4.4			15	4.2		
	4.2	4.47	2,237		4.0		
10	20.2				3.8		
	18.6				3.8		
	18.0				4.0	3.96	2,525
	20.4	19.3	518	13	5.8		
15	4.4				5.6		
	4.0				5.6	5.67	1,764
	4.4			15	4.0		
	4.2	4.25	2,353		4.0		
12	9.4				4.0	4.0	2,500
	9.2			10	18.0		
	8.0				16.8		
	7.4	8.50	1,176		17.0	17.3	578
12	6.6			15	4.0		
	6.8				4.0	4.0	2,500
	6.8	6.73	1,486	8	53.0		
15	3.8				59.0	56.0	179
	3.8	3.8	2,632	15	4.4		
8	44.6				4.4	4.4	2,273
	42.4	43.5	230	12	8.4		
15	3.8				8.0		
	4.0				7.8	8.07	1,239
	3.6	3.8	2,632	15	4.4		
7	98.0	98.0	102		4.4	4.4	2,273
15	3.8			14	5.0		
	3.8	3.8	2,632		5.0	5.0	2,000
9	24.6			15	4.6		
	23.8	24.2	413		4.6		
15	3.6				4.4		
	3.6				4.6	4.55	2,198
	3.6	3.6	2,778				

TABLE IV(*b*).

Alternating Potential.	Current in Arbitrary Units.
15 cells.	2,400
10	542
12	1,132
12	1,430 } 1,281
8	210
7	93
9	362
11	969
13	1,688
10	555
8	180
12	1,309
14	2,146

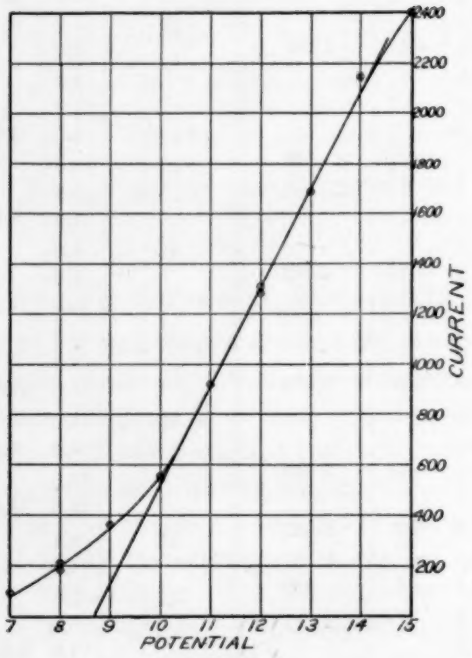

Fig. 6.

Now,

$$u = \frac{2nd^2}{P_0}$$

$$= 20.7 \text{ cm. per sec.},$$

and

$$v = \frac{u \times p}{760}$$

$$= \frac{20.7 \times 97.8}{760},$$

$$= 2.67 \text{ cm. per sec.}$$

The time for the ions to cross the field is

$$T = \frac{1}{2} \times \frac{1}{5{,}000} \times 104.4$$

$$= 0.01044 \text{ second.}$$

In a similar manner, the values of the mobility for other rates of alternation of the field were obtained using the same air pressure; and these are given in Table V.

TABLE V.

Dry Air. $p = 97.8$ *mm.* $t = 24°.0$ *C. Arc.*

T	u	v
0.0076	22.4	2.88
.0104	20.8	2.68
.0148	19.2	2.47
.0209	17.3	2.23
.0266	16.4	2.11

A set of results for dry air at atmospheric pressure and room temperature is given in Table VI.

TABLE VI.

Dry Air. $d = 19.235$ *mm. Arc Light.*

T	n	p	t	P_0	u	v
0.0077	64.5	739.0	19°.0	229.0	2.08	2.02
.0077	64.5	754.0	22.5	230.8	2.08	2.06
.0104	47.9	739.0	19.0	174.0	2.04	1.98
.0126	39.56	739.0	23.0	134.0	2.18	2.12
.0130	38.5	738.0	23.0	140.0	2.04	1.98
.0149	33.67	739.0	24.0	116.4	2.12	2.06
.0183	27.3	739.0	25.0	97.0	2.08	2.02
.0275	18.2	742.2	22.0	65.4	2.06	2.01
.0282	17.76	739.0	25.0	63.0	2.08	2.02
.0294	17.01	739.0	25.0	60.7	2.07	2.02
.0328	15.30	742.0	23.0	52.3	2.16	2.10
.0354	14.12	754.0	22.0	54.0	1.94	1.92
.0401	12.47	742.2	23.0	43.7	2.11	2.06
.0459	10.92	742.0	23.0	39.3	2.06	2.01

The graphical representation of the values of v for the various values of T is shown in Fig. 7. The curve in this case is a horizontal

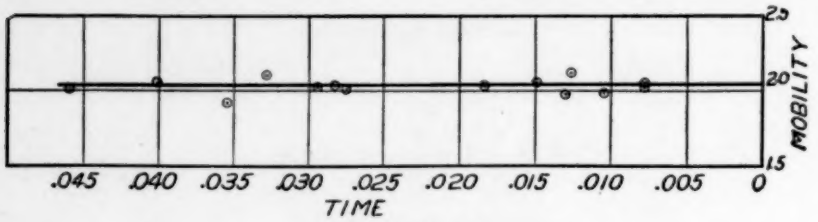

Fig. 7.

straight line which intersects the ordinate for $T = 0$ at a point $v = 2.04$, which is the value taken for the mobility.

A similar set of readings at atmospheric pressure was taken when the distance between the plates was 6.854 mm. In this set the illuminated area of the zinc plate was nearly the size of the gauze This may account for the greater slope of the curve on account of diffusion to the sides, vide § 4, 2. The readings are given in Table VII. and the corresponding curve is given in Fig. 8. The value of the mobility obtained from this set is 2.05 cm. per second.

TABLE VII.

Dry Air. $d = 6.854$ *mm. Arc Light.*

T	n	p	t	P_0	u	v
0.00776	64.4	738.0	23.0	28.28	2.14	2.07
.00795	62.8	725.0	22.0	27.2	2.16	2.07
.00795	62.9	722.0	24.0	27.7	2.13	2.02
.0090	55.56	738.0	23.5	24.8	2.10	2.05
.0103	48.5	722.0	24.0	21.7	2.10	2.00
.0117	44.7	722.0	24.0	20.2	2.08	1.98
.0135	37.1	722.0	25.0	16.37	2.13	2.03
.0146	34.13	738.0	23.5	15.67	2.05	1.99
.0172	29.0	735.0	24.0	14.09	1.94	1.88
.0188	26.6	738.0	23.0	12.76	1.96	1.90
.0203	24.63	738.0	23.0	11.70	1.98	1.92
.0230	21.7	738.0	23.0	10.44	1.95	1.90
.0233	21.46	738.0	23.0	10.30	1.96	1.90
.0266	18.8	738.0	23.5	9.21	1.92	1.86
.0253	19.76	735.0	24.0	9.23	2.01	1.94
.0280	17.83	738.0	23.0	7.66	2.18	2.12
.0343	14.58	722.0	24.0	7.16	1.92	1.82
.0362	13.8	735.0	24.0	6.88	1.89	1.82
.0404	21.39	738.0	23.0	5.77	2.02	1.95

Table VIII. gives the collected values of the mobility at atmospheric pressure, reduced to 760.0 mm., obtained under various conditions. In numbers 1 and 2 the apparatus used was that employed in the pressure experiments while in the numbers 3, 4 and 5, the apparatus used was the one constructed for the temperature experiments. In number 3 the gauze and the interior of the vessel were covered with lamp black whereby the effect of the reflected light

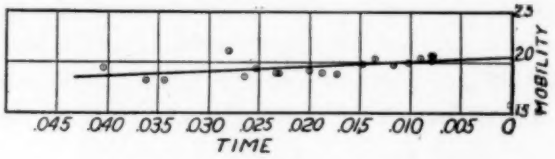

Fig. 8.

was reduced to a minimum. Zinc, platinum and brass were used as metals for the illuminated plate. It will be noticed from the table that the change of metal had no effect on the velocity. This was observed by Rutherford.[1] The agreement in the values of the mobility for the different distances between the parallel plates adds weight to the accuracy of the method.

TABLE VIII.

Dry Air. Atmospheric Pressure. Room Temperature.

No.	d	Metal.	v at 760 mm.	t	Remarks.
1	19.34 mm.	Zinc	2.04	20.0°	Pressure apparatus.
2	6.854	Zinc	2.05	23.5	
3	18.70	Platinum	2.05	21.0	Temperature apparatus.
4	18.70	Brass	2.05	24.0	
5	9.93	Brass	2.02	20.0	
			2.04 = mean		

The experiments with the variation of the intensity of light were performed with a fixed distance of 19.24 mm. between the plates and a fixed rate of alternation of 64.5 per second. The intensity of the light was changed in two ways, namely, either by screening off some of the light incident on the quartz lens or by changing the position of the arc relative to the apparatus. With weak intensities,

[1] Rutherford, E., Proc. Camb. Phil. Soc., IX., p. 401, 1898.

the motion of the gold-leaf of the electroscope was slow and fewer divisions on the scale were taken than generally (the scale divisions having a uniform value in the portion of the scale used), and with strong intensities an air condenser was put in parallel with the gauze to decrease the motion of the leaf. The intensity was calculated from the effect it produced and the one with the smallest effect was taken as unity. In order to compare the intensities, readings in each case were taken for a potential difference of 160 cells. Table IX. gives the results of the experiments. It will be noticed that the variation of the intensity has no effect on the value of the mobility. In numbers 6 and 7 the arc was close to the apparatus and the whole of the quartz plate was illuminated.

TABLE IX.

Dry Air. $d = 19.24$ *mm.* $n = 64.5$ *Alternations per Second.* *Potential* $= 160$ *Cells.* *Arc Used.* $p = 730.0$ *mm.* $t = 22°.0$ *C.*

No.	Deflection.	Time for the Deflection.	Capacity in E.S. Units.	Intensity of Light.	Mobility at 760 mm.
1	25–28 div.	34.0 sec.	30	1.00	2.05
2	25–27	17.1	30	1.30	2.05
3	25–28	19.0	30	1.79	2.04
4	25–27	10.0	30	2.27	2.05
5	25–30	25.9	68	4.96	2.04
6	25–30	11.55	57	9.30	2.02
7	25–30	11.7	295	47.5	2.02

The intensity generally used corresponds to that in number 4.

Change of Pressure in Air. — The values of the mobility at different pressures were obtained in the same manner as those obtained at atmospheric pressure.

The set of results given in Table X. is one of a number of such sets that were obtained and it was chosen because in this set the conditions of illumination were uniform, for which reason a comparison of the inclination curves for the different pressures can be made (vide Fig. 10). The column designated "tan a" represents the inclination of the straight line which determined the value of v at $T = 0$, and is the ratio of the increase of the mobility divided by the change of time to cross the field.

TABLE X.

Dry Air. $d = 19.34$ *mm. Arc Light.*

p	t	u	v	tan α
750.0 mm.	23.0° C.	2.07	2.04	1.0
547.4	21.5	2.79	2.01	2.0
316.0	22.0	4.93	2.05	2.8
215.3	24.0	7.49	2.12	11.8
160.0	19.5	10.9	2.30	19.6
125.0	23.0	15.2	2.50	27.1
97.8	24.0	24.6	3.16	37.6
77.0	23.0	42.9	4.34	62.5
51.8	21.0	90.0	6.14	116
34.0	24.0	180.0	8.05	178
16.0	24.0	470.0	9.90	230
8.8	26.5	1,800.0	20.8	614

The relation between the reduced mobility v and the pressure is shown in Fig. 9. From 760 mm. to 200 mm. the curve is linear

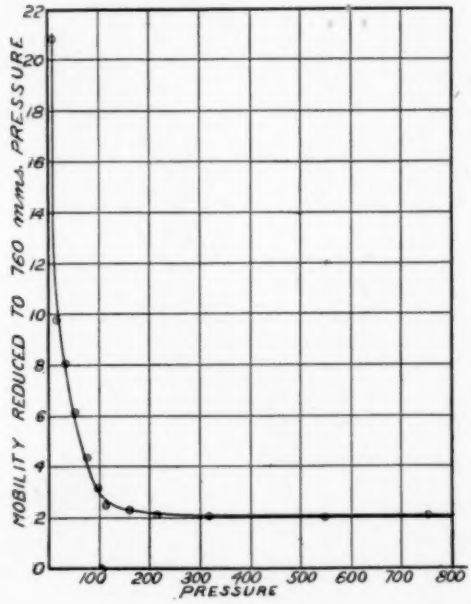

Fig. 9.

and nearly parallel to the axis of pressures, which indicates that the mobility u varies inversely with the pressure. At 160 mm. the

value v is 12 per cent. higher than at atmospheric pressure, at 125 mm. it is 22 per cent. higher, at 100 mm. it is 55 per cent. higher, at 77 mm. it is more than double the value at atmospheric pressure, and at 8.8 mm. it is ten times that value. The curve shows a marked bend at a pressure of about 110 mm. and below this pressure it rises rapidly. The mobility below this pressure changes far more rapidly than the inverse-pressure law indicates. The comparatively sudden change in the velocity at 110 mm. pressure is very suggestive of a sudden change in the constitution of the ion, as if, at this pressure, the complex structure suddenly disintegrated. As there is a sudden change in the mobility of the ions there should be a sudden change in their coefficient of diffusion. This phase of the problem was not studied, but the curve of Fig. 11, in which "tan a" is plotted against the pressure, may point in that direction.

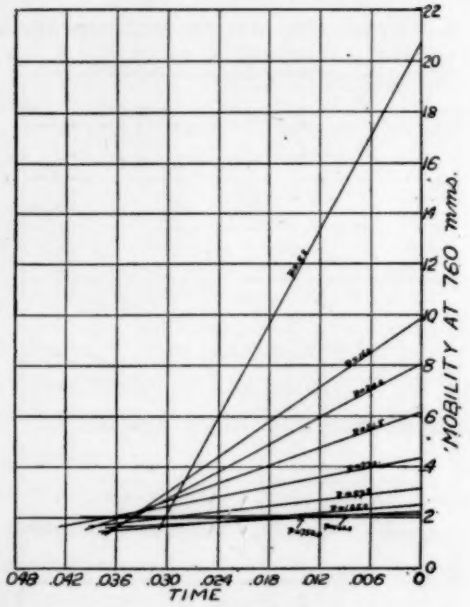

Fig. 10.

Dry Carbon Dioxid. — Experiments on the velocity of the negative ions in carbon dioxid at various pressures were performed in the same manner as the experiments on the velocity in air. Ordinary liquid carbon dioxid was used and on testing it by the absorption

method, it was found to be 99.6 per cent. pure . Several curves were obtained for the relation between the mobility reduced to 760 mm. and the pressure, all having the characteristic bend at low pressures noticed in the curves for air. All but one of the curves were like the one shown as curve *I* in Fig. 12, having the bend at about 150 mm. and rising much more suddenly than was the case with air. In the exceptional case noted, shown as curve *II*, Fig.

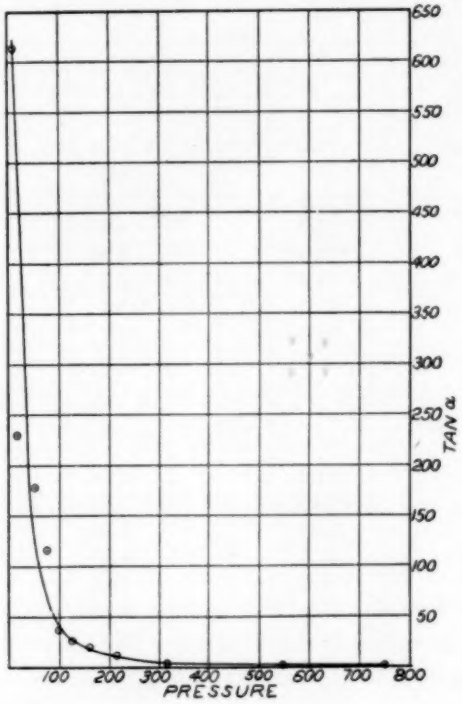

Fig. 11.

12, the bend is at a much lower pressure and the curve otherwise also resembles more closely the one for air. The reason for this is not known unless it be due to some impurities, for the gas used in this set was the last supply in the tank and its purity was unfortunately not tested. The results corresponding to the curves *I* and *II*, Fig. 12, are given in the table below.

For the curve *I* the per cent. of increase above that at atmospheric pressure is 80 per cent. at 154 mm., 170 per cent. at 118 mm.

and 600 per cent. at 88 mm., while for the curve *II* it is 24 per cent. at 176.6 mm., 50 per cent. at 87 mm. and 700 per cent. at 17 mm. The per cent. of increase in the value of v with the diminution of pressure over the value at atmospheric pressure is greater throughout in the case of carbon dioxid than in the case of air.

TABLE XI.

Dry Carbon Dioxid. Arc Light. $d = 19.34$ *mm.*

Curve I.

p	t	u	v
738.0 mm.	22.0° C.	1.04	1.01
362.0	21 5	2.22	1.06
257.0	22.5	3.72	1.26
197.3	21.0	4.65	1.20
154.0	23.0	8.93	1.81
118.0	23.0	17.7	2.74
118.0	23.0	17.4	2.69
88.5	24.0	57.5	6.70
66.9	24.0	222.0	19.6

Curve II.

738.0	22.0	1.04	1.01
501.2	20.5	1.66	1.09
362.0	20.0	2.20	1.05
176.6	21.0	5.37	1.25
139.0	21.0	7.43	1.36
109.5	21.0	9.56	1.38
87.0	21.0	13.2	1.51
52.4	20.0	33.5	2.31
20.0	21.0	100.5	3.70
17.1	21.0	366.0	8.24

Experiments with Moist Gases. — It was observed by Zeleny[1] that the presence of moisture in gases decreases the mobility of the negative ions. Professor Zeleny in his paper expresses the view that the molecules of aqueous vapor collect upon the negative ion which, thus loaded, necessarily moves slower. Similar observations on the decrease of the mobility of the ions in vapors of ether and alcohol

[1] Zeleny, J., Phil. Trans., A, 195, p. 193, 1900.

were made by Rutherford,[1] and recently Blanc[2] reported similar results.

Experiments with moist gases were performed at atmospheric pressure and room temperature. The gases, air and carbon dioxid, were saturated with aqueous vapor by passing them through a flask containing boiling water and then through a flask containing water at room temperature. A difficulty in carrying out the experiments

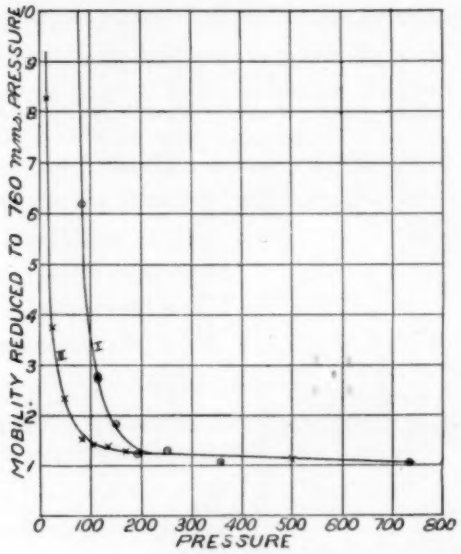

Fig. 12.

was at first encountered for zinc covered with a layer of moisture will not act photo-electrically. By increasing the intensity of the light, it was noticed that the gauze produced enough photo-electric effect (vide § 4, 1) to make it possible to take readings. The leaf of the electroscope became in these cases, of course, charged positively. This action of the brass wire gauze seemed strange in view of the fact that metals covered with moisture are reported to cease acting photo-electrically, as indeed zinc does. It may, therefore, be of interest to note that by covering the zinc with a sheet of brass, the photo-electric effect in gases saturated with water vapor appeared the same as in dry gases. The readings, however, were taken by

[1] Rutherford, E., Phil. Mag., VI., 2, p. 210, 1901.

[2] Blanc, A., J. de Physique, 4, 7, p. 825, 1908.

utilizing the effect from the gauze. The results for moist air are given in Table XII. and for moist carbon dioxid in Table XIII. The linear distribution of the mobilities gives a horizontal line, which in the case of moist air intersects the ordinate for $T = 0$ at $v = 1.64$ cm. per sec. and in the case of moist carbon dioxid at $v = 0.806$ cm. per sec. It will thus be noticed that the velocity of the negative ions both in moist air and in moist carbon dioxid is 20 per cent. below the value in dry air and in dry carbon dioxid, respectively.

TABLE XII.

Moist Air. Arc Light. Gauze = Source of Negative Ions. Pressure = 745.4 *mm. Temperature* = 26°.0 *C.*

T	u	v
0.0076	1.66	1.63
.0098	1.60	1.57
.0139	1.72	1.68
.0173	1.72	1.68
.0212	1.77	1.74
.0267	1.55	1.52

TABLE XIII.

Moist Carbon Dioxid. Arc Light. Gauze = Source of Negative Ions. Pressure = 740.0 *mm. Temperature* = 25°.0 *C.*

T	u	v
0.0270	0.824	0.802
.0218	.832	.800
.0175	.816	.795
.0138	.850	.828

§ 7. CHANGE OF TEMPERATURE EXPERIMENTS.

High Temperature. — The apparatus used in the final temperature experiments, both at high and low temperatures, is shown in Fig. 13. The gauze G was fastened by its wires to a piece of tubing T, 3 cm. in diameter, which was held in position by 3 quartz rods Q from brass blocks adjustable on the front face plate of the apparatus. The gauze was set so as to be in the plane of the inner surface of the plate, and it had a ring of air 1 mm. wide around it. The plate to be illuminated P was held in position by 3 glass rods R passing through cleaved collars. The front plate screwed into a brass cylinder B. The whole apparatus could be readily placed in position in the oven by an iron rod A screwed into the front

plate. The heating electric oven had a porcelain cylinder 600 mm. long and 80 mm. in diameter. The heating current was generally an alternating current. The interior of the porcelain cylinder was lined with a sheet of brass connected to earth so as to avoid induction effects from the heating current which were very marked when the screen was omitted.

The apparatus was placed in the middle of the oven. Several centrally perforated discs of asbestos were placed inside the oven at both ends of the apparatus and at some distance from each other, so as to break up any air currents inside the oven and to prevent changes of temperature.

The ends of the porcelain cylinder were closed quite tightly by means of brass covers, allowing only a small leak for the equalization of the pressure with the outside. One of these covers was provided with a quartz plate to allow transmission of the light, and an ebonite plug (quartz and glass tubes were also used instead of the ebonite plug in some experiments) for the wire leading to the electroscope; the other cover had a glass window (used for viewing the interior) and two tubes used respectively for a wire leading to the secohmmeter and for a clay tube containing the thermo-couple used for measuring the temperature. The junction was placed in contact with the rear central portion of the illuminated plate.

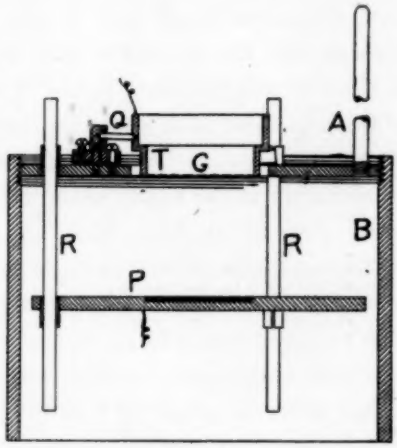

Fig. 13.

Observations were not carried above 425° C. because of a leak through the quartz rods at higher temperatures. The leak of an electric charge from the electroscope through the quartz rods was studied and found to increase with the increase of temperature, becoming very fast indeed at about 425° C. It was found to obey an exponential law, and for this reason it was utilized in taking a few readings at high temperatures by the constant deflection method.

The readings so taken give the values in numbers 1, 2 and 9, Table XIV. The remaining readings were taken by the rate method, as before.

Low Temperatures. — The apparatus was placed in a tin can through whose cover all the wires passed out. Between the apparatus and the cover were several discs of paper to break up currents of air. Phosphoric anhydride was placed at the bottom of the can and also in a ring at about the middle portion of the can. A tube through the cover and leading to the bottom of the can was also provided for passing dry air into the can previous to any experiment. The quartz plate in the cover of the can was kept dry by blowing dry air over it continually during an experiment.

The low temperatures were obtained in no. 18 (Table XIV.) by packing the can in a freezing mixture of ice and salt; in no. 23 by immersion into liquid air; in nos. 19–22 by lowering the liquid air flask so that the apparatus was above the liquid air but the bottom of the can still remained in the liquid air.[1] The lowering or raising of the liquid air flask could be done by very small amounts and the temperature could be kept constant within 5° C. However, the temperature at the upper plate differed from the temperature at the lower plate by as much as 12° C. and it is possible that some convection currents existed in these experiments. Such currents would move upwards in the center of the apparatus and would bring the ions to the gauze sooner than would otherwise be the case. This was somewhat apparent from a small downward slope in the curve for the different values of T in the experiments given by nos. 19–22. The temperature was measured by two thermo-junctions of iron and nickel wires; one of them rested on the top of the upper portion of the apparatus while the other rested against the side of the apparatus at about the position of the illuminated plate. The mean value of the two temperature readings was used as the temperature of the gas in the experiment. The calibration at low temperatures was done by means of liquid air, the liquid air temperature was obtained by the density method[2] which gave — 193°.4 C., while a pentane thermometer read in the same air — 193°.0 C.; intermediate calibration

[1] Compare Zeleny, J., PHYS. REV., XXIV., p. 42.

[2] U. Behn und F. Kiebitz, Ann. d. Phys., 4 S., 12, p. 421, 1903.

points were obtained by placing the pentane thermometer and the junction in a tube of pentane and raising the tube out of the liquid air to different points, the pentane being constantly stirred.

The illumination was brought about by reflecting the light by means of a polished brass plate downward into the apparatus. The results for all the temperatures tried are given in Table XIV.

TABLE XIV.

Dry Air.

No.	Absolute Temperature.	p	u	v	V	d	Plate.
1	698°	744.0	5.72	5.60	2.19	18.70 mm.	Brass.
2	648	745.0	5.60	5.50	2.32	"	Brass.
3	570	746.0	4.57	4.48	2.15	"	Platinum.
4	540	746.0	4.43	4.35	2.20	"	Platinum.
5	503	741.0	4.12	4.02	2.18	"	Platinum.
6	468	732.0	4.08	3.94	2.30	"	Brass.
7	463	746.0	3.80	3.73	2.20	"	Platinum.
8	428	734.0	3.82	3.68	2.35	"	Brass.
9	416	742.0	3.46	3.38	2.27	"	Brass.
10	409	738.4	3.42	3.32	2.22	"	Platinum.
11	388	733.0	3.02	2.92	2.05	"	Platinum.
12	378	742.0	2.84	2.77	2.00	"	Platinum.
13	360	744.0	2.69	2.64	2.00	"	Platinum.
14	340	731.0	2.72	2.62	2.10	"	Brass.
15	335	737.0	2.58	2.50	2.04	"	Platinum.
16	300	732.6	2.18	2.10	1.91	"	Brass.
17	296	738.0	2.10	2.05	1.88	"	Brass.
18	268	738.0	1.853	1.80	1.83	9.93	Brass.
19	237	738.0	1.588	1.54	1.77	"	Brass.
20	202	740.2	1.160	1.13	1.53	"	Brass.
21	180	738.0	0.896	0.87	1.32	"	Brass.
22	149	741.2	0.638	0.622	1.14	"	Brass.
23	84.5	746.0	0.226	0.222	0.717	"	Brass.

The mobility reduced to normal pressure is plotted against the temperature in Fig. 14. It will be noticed that the points are very nearly on a straight line which intersects the temperature axis at about 80° absolute. Phillips (loc. cit.) using a shorter range, obtained a less inclined straight line.

The above curve does not give direct information about any changes that may take place in the ion with change of temperature, for, although the values were all obtained at atmospheric pressure, the

density of the gas was markedly different at the different temperatures. The mobility v for each temperature was reduced therefore to the

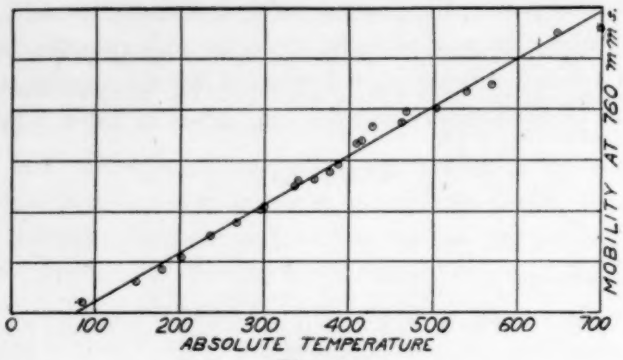

Fig. 14.

density at 0° C., on the supposition that the mobility varies inversely as the density of the gas. The values thus obtained are given in the above table in the column marked V, and they are plotted against their temperatures in Fig. 15. From 700 down to 400 degrees absolute there is no change in the value of V, but below 400 it diminishes until at 84.5 degrees absolute it is only one third of the value at the higher temperatures. This decrease in the

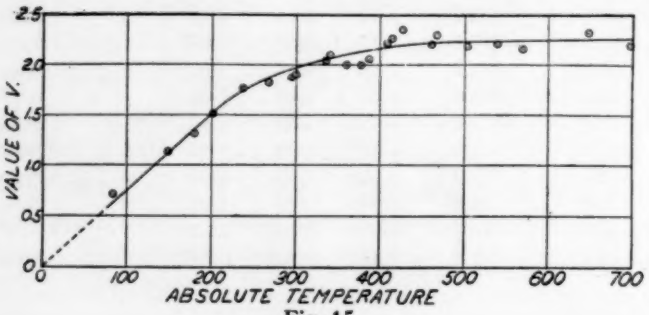

Fig. 15.

mobility of the ions indicates that at the lower temperatures the cluster of molecules about the ion becomes larger on the average as the temperature is lowered.

§ 8. SUMMARY AND CONCLUSION.

1. At atmospheric pressure and room temperature the mobility of the ions produced by ultra-violet light, when reduced to 760

mm. pressure, was found to be 2.04 cm. per sec. per volt per cm. for dry air, and 1.01 cm. per sec. for dry carbon dioxid. In air saturated with water vapor at 26°.0 C. the reduced value was 1.64 cm. per sec. and in carbon dioxid saturated with water vapor at 25°.0 C. the reduced value was 0.806 cm. per sec.

2. The mobility of the negative ions in air at ordinary room conditions is the same whether the metal illuminated by the ultra-violet light is zinc, platinum or brass.

3. With changing pressure the mobility of the ions, in both dry air and dry carbon dioxid, varies inversely with the pressure from 760 mm. down to about 200 mm., so that the product of the mobility by the pressure is constant.

4. In dry air below 200 mm. the product of the mobility by the pressure increases as the pressure is reduced, the increase being slow at first but very sudden at about 100 mm. so that at 8.8 mm. the product was found to be ten times as great as that at atmospheric pressure. This result indicates that below 200 mm. the size of the ion is increasingly smaller as the pressure is reduced.

5. In dry carbon dioxid below 200 mm. there is likewise a sudden increase in the product of the mobility by the pressure, but this occurs at a somewhat higher pressure than in air.

6. With a change of temperature from 84.5 to 698.0 degrees absolute, the mobility of the negative ions in dry air at atmospheric pressure was found to increase uniformly with rise of temperature. When reduced to a common gas density, the value obtained for the mobility remains unchanged from 700° to 400° absolute, but below that temperature it diminishes until at the temperature of liquid air it is only about one third of its value at the higher temperatures. In this region the cluster of molecules forming the ion increases in size, therefore, as the temperature is lowered.

In conclusion, I desire to express my deep gratitude to Professor John Zeleny, who suggested this investigation and under whose supervision these experiments were carried out, for the valuable advice from him, and to Dean Frederick S. Jones for the kindly interest he has shown in my work.

PHYSICAL LABORATORY,
UNIVERSITY OF MINNESOTA,
August 23, 1909.

SCATTERED LIGHT IN SPECTROPHOTOMETRY AND A NEW FORM OF SPECTROPHOTOMETER.

BY HERBERT E. IVES.

RECENTLY, in making some spectrophotometric measurements of artificial light sources in terms of daylight, the writer's attention was called to the importance of scattered light as a source of error in spectrophotometry. Scattered light is practically impossible to avoid in optical instruments. For this reason it is surprising that it receives next to no attention in the design or the published descriptions of the manipulation of spectrophotometers. In such instruments as the Brace and Lummer-Brodhun diaphragms in the collimator and telescope tubes constitute the sum of the precautions taken to avoid stray light. Yet under certain circumstances, to be outlined below, such precautions are insufficient; in fact, only by the use of other forms of instruments can the stray light error be entirely eliminated.

The first essential of a spectrophotometer is complete symmetry; the light from the two sources must be subject to identical treatment in its passage through the instrument to the eye. This symmetry must hold not only when the two sources are identical, but when they are different in special character. It is in this latter requirement that some of the present forms are deficient. Scattered light, when present, is present usually in different quantity and quality in the fields due to the two sources. This deficiency becomes apparent usually only on measuring light sources as different in character as daylight and the yellow artificial illuminants, in which case considerable errors are possible.

The source of this scattered light, its amount in different types of spectrophotometers, and the means to obviate it, form the subject of the present note.

In a spectrophotometer with a perfect system of diaphragms the remaining scattered light — visible as an illumination of the in-

strument field if monochromatic light is used and the eye is observing at another wave-length — is due to light from the lens and prism surfaces, either from dust and scratches or from "ghosts." The peculiarity of this light (and also scattered light due to imperfect diaphragms) is that it is proportional not to the intensity of the wave-length under observation but to the total amount of light of all colors striking the scattering surface. When making observations at the ends of the spectrum, for instance, what one observes, even in the newest and best instruments, will be the deep red or blue superposed on a background of gray due to scattering. The older the instrument, the more dust or film on lens surfaces, or the more numerous the lens ghosts, the larger the proportion of the total light is this scattered background. This is especially noticeable in a spectrophotometer if a large quantity of light is used in an attempt to secure measurements in the fainter portions of the spectrum.

Now this scattered light can or cannot cause errors, depending on the following principle: If the scattered light is spread equally over the two photometric fields to be compared, it is harmless; if it is present on one side alone it results in error. In the former case a loss of photometric sensibility results which is not desirable, but is far less undesirable than the error which arises in the latter case from comparing the colored light of one side with the colored light plus scattered light of the other.

In undertaking the measurements above referred to the writer had available a Lummer-Brodhun spectrophotometer and a spectrometer converted into a spectrophotometer by the use of a right angle prism device at the slit. The chief difference in the instruments — which are representatives of two usual types of spectrophotometers — is that in the Lummer-Brodhun the spectra are focused on the eye; hence the prism face is seen of one color. In the other instrument two adjacent spectra are viewed by an eyepiece. In the Lummer-Brodhun instrument the division of the beams of light from the two sources is effected by the use of two collimators, and the photometric field is a Lummer-Brodhun prism between the collimator and the dispersing prism. In the other instrument the two beams of light are divided at the slit, but pass over identical

paths through one collimator to the image plane of the telescope.

Were there no other factors to be considered than ease of observation the Lummer-Brodhun instrument would have been chosen, because the large monochromatic surface and extended dividing lines which are observed in that type permit of more accurate settings than does the narrow strip from the adjacent spectra on which comparisons are made in the adapted spectrometer. When, however, observations were made on two sources with a steep spectral gradient with respect to each other, for instance a light weak in red and strong in blue, against one strong in red and weak in blue, the following condition was found: At the red end of the spectrum it was necessary to admit so much of the light of the red deficient source that a mist of gray light was caused on the corresponding field by the large amount of the green and blue admitted. At the blue end the scattered light was in the field corresponding to the other source. At each end of the spectrum, therefore, one of the fields was grayer than the other and an intensity match would not be a true one. This grayness, it should be noted, may easily be confused with the lack of color match caused by very wide slits, with sources of steep spectral gradient. The effect of scattered light of this kind, present on one side of the instrument and not on the other, is in general to make the two sources measured appear nearer alike in character. Anomalous results at the ends of the spectrum may also be expected.

Attempts to eliminate the unsymmetrical illumination on the two sides met with partial success. By having the collimator lenses and Lummer-Brodhun prism scrupulously clean and by providing additional diaphragms outside the slits, large enough to place all the interior diaphragms in shadow, considerable improvement was produced. By using colored glasses of tints to absorb the portion of the spectrum not being observed (this, of course, changed the values of the readings) the improvement was still greater, and for most purposes this method would probably be perfectly satisfactory. It was, however, decided to use the instrument giving two juxtaposed spectra because the scattered light trouble appeared to be entirely absent. Scattered light was present; but with this important distinction, that the light forming the two spectra, in its

passage to the image had filled the whole surfaces of all the lenses and prisms, hence the scattered light was spread equally over both images and the dividing line, thereby merely resulting in a loss of sensibility. Interposition of a colored glass at the ends of the spectrum made no difference in the values of the readings. There was, therefore, no uncertainty as to whether the disturbing factor had been entirely eliminated or in the periods between observations had changed in amount.

As mentioned above, the spectrophotometer in which two adjacent spectra are viewed is not sensitive because the dividing edge for any strip of the spectra such as could be compared, is extremely narrow. On the other hand, in existing designs of spectrophotometers in which the prism face is observed by monochromatic light the two beams of light usually pass through two separate collimators. In all, the prism, biprism or other device forming the photometric field, is a material object. It therefore separates not only the direct but the scattered light of each half of the field from the other half. In this class belong the Lummer-Brodhun and the Brace instruments. The Koenig spectrophotometer which separates the light partly at the slit and partly by a biprism, after passage through the single collimator, lies between the two classes.[1]

In an attempt to secure the advantage of both styles of spectrophotometer a new design has recently been constructed. The principles of this are: (1) That the light from both sources should go through one collimator and dispersive system in such manner that all surfaces which could cause scattering would receive light from both sources equally. (2) That the photometric plane should be a virtual one in space, through which the background of scattering could be seen behind each field equally, no matter from which side the scattered light originated.

A, Fig. 1, is a Hilger constant deviation wave-length spectrometer. At 1 is placed any convenient device for forming a divided photometric field, such as a plaster-of-paris wedge, or a Lummer-Brodhun contrast prism. As set up a large and small right angle prism were cemented together, the face *b* being entirely silvered,

[1] The writer has had no opportunity to work with a Koenig spectrophotometer, but study of its construction would indicate it to be practically free from the possibility of scattered light asymmetry.

the face *a* silvered half way up. 6 and 7 are the two sources to be compared, which must be extended, preferably white surfaces illuminated by the lights compared. At 2 (the slit) is a convex lens,

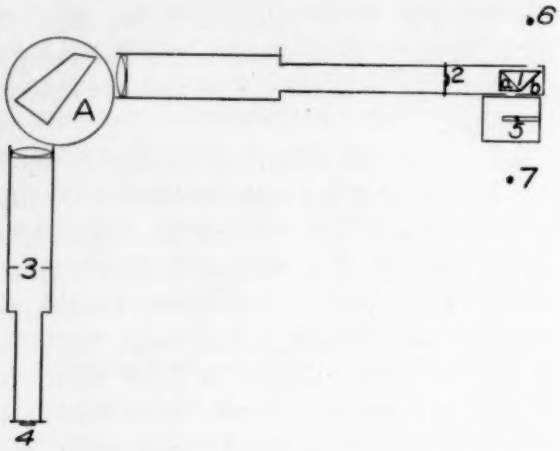

Fig. 1.

where distance and focal length are such that it forms, with the collimator and telescope lenses, an image of the prism face *a* at some place in the telescope tube 3, as distant as possible from the lenses and prism of the instrument. 5 is a Brodhun sector disc for reducing the intensity of one source by a measurable amount. At 4 is a spectacle lens to focus the image at 3.

Now, if the dividing line at *a* is perpendicular to the length of the slit at 2 a sharp image of it will be formed at 3 with any slit width practicable to work with. (Because of diffraction, lines parallel to the slit lose their sharpness with a very narrow slit.) Further, if the slit of the spectrophotometer be made long (as long as the diameter of the collimator lens for the best effect) the beam of light coming from any part of *a* is spread over a large area of lenses and prisms, and if dust or scratches be present to cause scattering, the scattered light is seen as a background to the image at 3. By properly choosing the length of slit and place of forming the image, the condition found in the second type of instrument described above is obtained, namely, the scattered light from all the material

surfaces of the instrument is spread equally over the two photometric fields at their dividing line.[1]

Severe tests of this instrument, such as directly viewing incandescent lamp filaments and an acetylene flame, have proved it to have the characteristics for which it was designed, not only when all surfaces are perfectly clean and new, but when purposely covered with dust, to imitate the conditions which might occur after long use.

In working with this spectrophotometer the substitution method was always used, to avoid any errors due to selective absorption in the Brodhun sector, or silvered prism surfaces. This should, of course, always be done in spectrophotometry where accuracy is desired. A possible objection that may be raised to the instrument —that it is impossible to vary the relative intensities by changing two slit openings—may be dismissed on similar ground. The range of slit openings necessary to make matches with sources very different in color is altogether too great for accuracy unless the dispersion is large.

The objections may be made to the discussion above that measurements should never be made with instruments not in perfect condition, and that the errors indicated are small except where the light sources measured are so different that one is less concerned with absolute accuracy than with the relative order of magnitude of the two. The objections are perfectly valid. Nevertheless, under certain conditions, such as the use of portable instruments for daylight measurements, laboratory conditions of cleanliness and ability to shield an instrument from light cannot be obtained. When so used, an instrument which loses its symmetry with the presence of scattered light may give results in error by an indefinite and often large amount. Prudence would indicate therefore that when very differently colored sources are compared under other than the most favorable laboratory conditions an instrument should be used which preserves its symmetry. Or if a form is used in which scattered light destroys the symmetry, the instrument should

[1] In practice it proved well to have the photometric dividing surface quite near the front slit, using a short focused lens. Otherwise the Brodhun sector with its rather small angular opening, cuts the field of vision.

have its diaphragms looked to with especial care, and, for safety, colored glasses should be used as indicated above.

The object of this note has been to call attention to the fact that certain spectrophotometers which are symmetrical when the two sources observed are the same in spectral character, may become unsymmetrical when sources different in character are compared, if scattered light is present. The two types of instrument in which this defect is and is not present, are indicated. An instrument possessing the large monochromatic field of the Lummer-Brodhun and Brace instruments, but which does not become unsymmetrical in the presence of stray light, is described.[1]

PHYSICAL LABORATORY OF THE NATIONAL ELECTRIC LAMP ASSOCIATION,
CLEVELAND, O.

[1] Since the construction of the above instrument a description of a similar instrument is given by M. J. Thovert in the Journal de Physique for November, 1909. It is described as a convenient means of altering an ordinary spectroscope to a spectrophotometer and dispensing with the double collimator of the Lummer-Brodhun instrument while obtaining a similar field. No discussion is given, however, of its behavior toward scattered light or the arrangement of image, slit length, etc., to avoid scattered light effects.

THE ELECTRICAL CONDUCTIVITY OF FLUORESCENT ANTHRACENE VAPOR.

By H. E. Howe.

THE following paper is an account of an attempt to determine whether fluorescence has any effect on the electrical conductivity of anthracene vapor. Although the results of the experiment were negative, it being impossible to detect any conductivity of the vapor either unilluminated or fluorescent, the accuracy of the work was such as to set a rather definite upper limit for any effect that may be present, and the results are presented with the hope that some experimenter may be able to apply an improvement of the method to the same substance or, preferably, to others that might be expected to show the effect sought for.

The idea of testing the effect of fluorescence on the conductivity of a vapor was suggested to the writer by the paper of Nichols and Merritt[1] in which they reported an increase of 1.1 per cent. in the conductivity of an alcoholic solution of eosin and smaller changes for solutions of fluorescein, rhodamin, cyanin and naphthalin roth, the effect being ascribed to a dissociation of the X-ray type. The final form of the experiment, which was the result of several preliminary attempts, was carried out under the guidance of Professors Nichols and Merritt, and the writer wishes to thank them here for their many very useful suggestions and for their patient encouragement in the face of difficulties.

The expectation of a change in conductivity during fluorescence is based on the theory that fluorescence is a dissociation phenomenon. Whether this dissociation is such as to produce any such effect is as yet undetermined. Some of the theories and experiments that are for or against the assumption of a change will be briefly mentioned.

In the work of Nichols and Merritt with solutions, a Wheatstone-

[1] Nichols and Merritt, PHYS. REV., Vol. 19, p. 296, 1904.

bridge method was used and difficulties were encountered due to heating on illumination and to the difficulty of eliminating disturbances due to polarization. Since the appearance of their paper the experiment has been repeated by Camichel,[1] who found no effect that could not be accounted for by heating. Regner[2] set 0.1 per cent. as the upper limit of change for solutions of eosin and fluorescein. More recently Hodge[3] and Goldman[4] have shown separately that the effect found by Nichols and Merritt was due to an electromotive force produced by light at the electrodes of the cell, and that no measurable change of conductivity was present.

Little work has been done on vapors. Henry[5] could find no conduction of iodine vapor due to light. On the other hand, J. J. Thomson[6] states, without giving reference, that light increases the conductivity of sodium vapor. Wiedemann and Schmidt,[7] in their paper in which they propose the dissociation theory, say that this does not call for any ionization in the case of fluorescent vapors.

The desirability of anthracene vapor for this experiment is seen from the following considerations:

1. The vapor is strongly fluorescent.

2. It has banded absorption and fluorescent spectra[8] lying in the region 320–400 $\mu\mu$, light of these wave-lengths being transmitted by the glass used in this experiment. Stark,[9] in his work on band spectra, has concluded that fluorescence and photoelectric properties are intimately associated with absorption in bands shaded toward the red, and that the "carriers" of the band spectra are the negative electrons, which are pulled out of their normal position by the incident light, and upon their return to the position of equilibrium liberate the energy of the fluorescent light.

3. If the separation of the electron is complete, photoelectric properties would be exhibited. It is thus that Stark and Steubing

[1] Camichel, Jour. de Phys., 4, p. 873, 1905.
[2] Regner, Phys. Zeit., 4, p. 862, 1903.
[3] Hodge. PHYS. REV., 28, p. 25, 1908.
[4] Goldman, Ann. der Phys., 27, p. 332, 1908.
[5] Henry, Proc. Camb. Soc., 9, p. 319, 1897.
[6] Thomson, Cond. through Gases, p. 213.
[7] Wiedemann and Schmidt, Ann. der Phys., 56, p. 201, 1895.
[8] Elston, Astr. Jour., 25, p. 155, 1907.
[9] Stark, Phys. Zeit., 8, p. 81, 1907.

explain the fluorescence of solid anthracene.[1] After investigating a number of substances, they say: "It is highly probable that for organic substances, at least, the photoelectric effect and fluorescence are intimately connected with each other." Hence it would seem that the vapor of anthracene would be as likely as any vapor to possess photoelectric properties.

Apparatus.

The glass tube used to contain the anthracene is shown in Fig. 1. The larger part of the tube was 15 cm. long and 2.5 cm. in diameter. The electrodes between which the current passes consisted of an outer

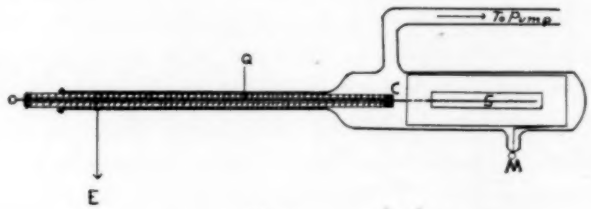

Fig. 1.

aluminum cylinder, to which connection was made by sealing a platinum wire through the glass at M, and an inner brass wire supported by a quartz tube Q and visible through the slit in the outer electrode.

The quartz tube served as insulation for the brass wire electrode. Further protection was afforded by a deposit of silver on the inside of the glass tube around the quartz, this silver layer extending around to the outside of the open end where it was wrapped with tinfoil and grounded to form a guard-ring. Thus no charge could leak over the glass surface from the outer electrode.

The openings at the outer end of the quartz tube were sealed with de Kochtinsky cement. This would not stand heating, and the furnace was arranged to enclose only the large part of the tube (see dotted outline in Fig. 2). It was necessary to have the quartz tube fit snugly in place and to provide a tight-fitting cap C at the inner end in order to prevent the sublimation of the anthracene to the colder parts of the tube.

The tube, after being charged with anthracene, was exhausted to

[1] Stark and Steubing, Phys. Zeit., 9, p. 481, 1908. Also, Pochettino, Nuo. Cim., 15, p. 171, 1906.

a pressure of a few tenths of a millimeter, sealed off, and heated electrically. Light from a carbon arc A was converged by the lens L, and could be passed into the furnace through a mica window or could be cut off by the screen S. When the light was on, a bright cone of violet fluorescence could be seen in the center of the tube.

The outer electrode was charged from a storage battery B, and the rate at which the inner electrode acquired a charge was measured by means of a sensitive Dolezalek electrometer, which was enclosed

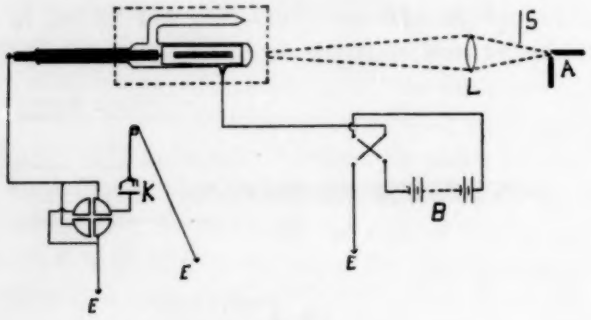

Fig. 2.

in a wire cage to protect it from the electrostatic disturbances. The end of the anthracene tube projected through a hole in this cage, making the protection of the inner electrode practically perfect.

The electrometer needle was charged to a constant potential (in most of the work this was 60 volts), one pair of quadrants was grounded and the other pair connected to the wire electrode. This pair could be grounded or insulated at will be means of the key K. When K is raised the motion of the needle is noted by observing on a ground-glass scale the image of a lamp filament formed by the small concave electrometer mirror. The current can be calculated from the known constants of the electrometer.

If V_q be the potential of the charging quadrants;
K be the deflection when V_q is one volt;
C be the capacity of the charging system;
Q, the charge; D, the deflection; I, the current; then

$$D = K \times V_q \quad \text{and} \quad Q = C V_q.$$
$$I = dQ/dt = C \times d V/dt = K \times C \times dD/dt$$

on the assumptions that K is the same for the moving needle as for the needle at rest and that C does not change with the position of the needle. Such assumptions are allowable for slow motion and small deflections.

Observations and Results.

$K = 375$ mm. on a scale one meter distant, when the potential of the needle was 60 volts.

C was determined by dividing the charge with a coaxial cylinder condenser of 30 cm. capacity, and was found to be 45 cm. or 5×10^{-5} microfarads.

A charging rate of 1 division per second could easily be observed if definite. This would mean a current 1.3×10^{-13} amperes. The insulation was such that the rate of leak when charged to 50 div. deflection was about 10 div. per minute, or one sixth the rate mentioned as easily measurable for charging.

At the low pressure used, anthracene vaporizes sufficiently to show fluorescence between 200° and 250° C. "90 per cent. sublimed" anthracene was used without attempt at purification as it was easily obtainable and the presence of impurities in the material does not seem to affect the fluorescence of the vapor. No attempt was made to shield the electrodes from the light scattered by the end of the tube, nor to use monochromatic light.

In liquids there is an electrode photoelectric effect, dependent upon which of the electrodes is illuminated. The possibility of the existence of such an effect in the vapor was not considered in this experiment.

In most of the work, the outer electrode was charged to 120 volts from an ordinary storage battery. K was raised and the rate of motion noted for the unilluminated tube. This was repeated with the light on.

When the tube was newly made up the electrometer remained quiet under all conditions, except for an occasional drift of not more than 1 division in 5 seconds. In the earlier work, after a few heatings, the electrometer began showing a tendency to rise rather quickly to a more or less definite deflection, regardless of conditions of potential or illumination. This peculiar effect varied from run to run and became very great in a case or two when the cement

with which the tube was sealed cracked and admitted air. A brown deposit was then left in the tube, apparently the result of a combination of the oxygen of the air with the anthracene.

A possible explanation of this attainment of a steady deflection even when the outer electrode was earthed is that the product of the decomposition of the anthracene is deposited on the quartz tube separating the silver guard-ring from the inner electrode and forms with these two metals a sort of voltaic cell. This "cell" had a very high temperature coefficient and in some cases the E.M.F. was so great as to throw the spot of light off the scale.

After several trials it was found possible, by taking great care to prevent the entrance of air, to get almost entirely rid of this effect. When this was possible the electrometer behaved normally.

No ordinary conduction was found. If the light had any effect it was too small to be detected. Thinking that the vapor under the action of the light might be almost ionized, an attempt was made to help out the ionization by exposing the vapor to the action of a small sample of radium bromide. The ionizing rays from this substance did not pass through the glass sufficiently to be of any use.

Higher potential was obtained by making up a set of small lead-sulphuric acid storage cells in test-tubes. This battery, when put in series with the one already at hand, gave from 360 to 540 volts, depending upon the condition of the small cells. The sensibility was increased by charging the electrometer needle to 120 volts. With the greater sensitiveness and the unsteady potential furnished by the cells, the electrometer wandered more or less in the neighborhood of the zero, but still did not indicate any steady rate of charging such as would have been evident had there been any considerable conductivity.

In the freshly exhausted tube the pressure was so low that the application of 400 volts caused a continuous luminous discharge through the tube, but this soon disappeared as the pressure rose due to the vaporization of the anthracene.

The number of trials was great enough to leave no doubt as to the behavior of the vapor under the various conditions mentioned.

Conclusions.

1. The conductivity of anthracene vapor at the temperature and density used in this experiment is too small to measure in the manner described.

2. The effect of fluorescence, if any exists, is too small to be found in this way.

The rate of leak of the electrometer system, while small, might mask a very slight effect. This matter, as well as the effect of pressure and temperature and of screening off the white light from the carbons of the arc, might be made the subject of any further investigation with this or another fluorescent vapor.

Physical Laboratory,
Cornell University.

THE RECTIFYING EFFECT IN POINT AND PLANE DISCHARGE.

BY R. F. EARHART AND CHAS. H. LAKE.

IN this investigation the authors have sought to secure quantitative measurements on the rectifying effect between an electrified point and a plane.

It has been known for some time that when an electrified point is separated from a plane positively electrified a sufficient potential difference may be attained to produce a discharge, and if the point is positive the potential difference required for the discharge will be greater than if the point is negatively electrified.

In "Conduction of Electricity through Gases" J. J. Thomson quotes measurements from observations made by several experimenters, but as the minimum potential varies with the sharpness of the point used it is very hard to make comparisons except with different pressures and different distances of the electrodes when the same point is used. Tamm[1] found that the minimum potential required to cause a perceptible leak between a point and a plane several centimeters removed, at atmospheric pressure, was 2,140 volts when the point was electrified negatively and 3,760 volts when the point was positive.

Results of observations made by Röntgen,[2] Precht,[3] Gorton and Warburg[4] are also recorded. These observations were made at pressures ranging between atmospheric pressure and a pressure of 10 centimeters of mercury, for a number of gases including air. In air at atmospheric pressure Precht found the minimum potential necessary to produce a discharge for point positive to be 2,730 volts and for point negative 2,050 volts.

In a previous paper published in the *Philosophical Magazine*,

[1] Tamm, Ann. der Phys., VI., p. 259, 1901.
[2] Röntgen, Göttingen Nach., 1878, p. 390.
[3] Precht, Wied. Ann., XLIX., p. 150, 1893.
[4] Gorton and Warburg, Ann. der Phys., 1905.

July, 1908, the results were given for a series of observations on the "Discharge from an Electrified Point and the Nature of the Discharge occurring through very small Distances."[1] The distances ranged from one to one hundred wave-lengths of sodium light and the ionizing potential for a point and a plane was found to be about 338 volts in air. The critical distance was greater for a point and plane than for two plane electrodes. In view of these results it seemed advisable to extend the work, using the luminous discharge and a greater range of distances and pressures.

In Fig. 1 is shown a cross-section of the discharge chamber. The

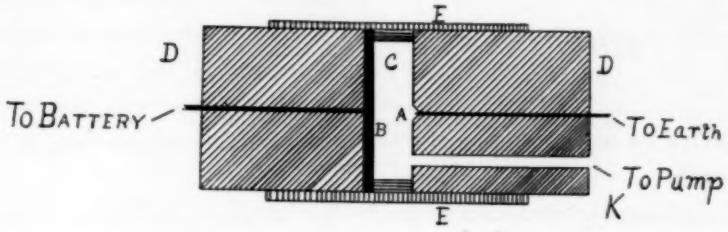

Fig. 1.

electrodes consisted of a plane brass plate B 3.5 cm. in diameter, which was fastened to a plug of red fiber D, and a small platinum wire slightly rounded at the point and firmly set in red fiber so that the end would be just even with the plane surface of the fiber. As shown in the figure the pieces of fiber were turned to fit the glass tube EE and further served to confine the gas in the chamber C. The piece of fiber in which the wire electrode was set was bored with a small hole K for the removal of the gas. For the purpose of making the joints air tight the Khotinski cement was used. The distances between the electrodes were determined by fiber rings carefully ground until they were accurate to one one-hundredth of a millimeter. The chamber was then connected in series with a drying chamber which had a capacity of about one and a half liters, a McLeod gauge and an air pump. A constant supply of phosphor pentoxide was kept in the drying chamber. A battery of 600 storage cells was used as a source to obtain the potential differences required in the work and a carefully calibrated Weston voltmeter with a suitable multiplier was used to measure them.

[1] Earhart, Phil. Mag., July, 1908.

The diagram in Fig. 2 shows the arrangement of the apparatus. One terminal of the battery is earthed direct; the other is connected through a liquid resistance R to one electrode of the discharge chamber and the voltmeter which is in parallel with the discharge chamber. The other electrode of the discharge chamber and the other terminal of the voltmeter are connected to earth. With this arrangement it is quite easy to make the point or the plate electrode either positive or negative by interchanging the earth and battery connections of the chamber.

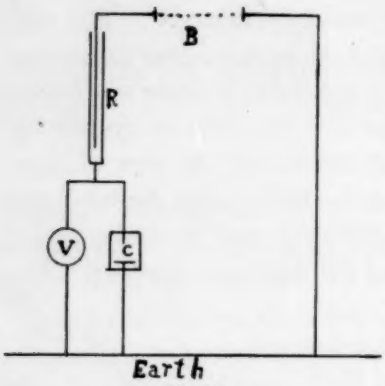

Fig. 2.

In making the measurements the potential was increased by small steps and sufficient time allowed to ascertain whether or not a discharge would occur before it was increased. The passage of the discharge could be readily detected by a sudden dropping off in the

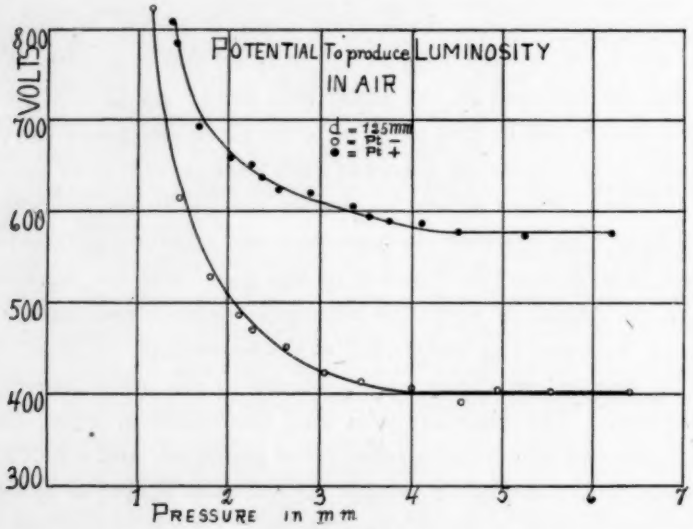

Fig. 3.

voltmeter reading and the cessation of the discharge could likewise be noted by a sudden increase in the voltmeter reading. In order to insure a greater degree of certainty as to the beginning of the

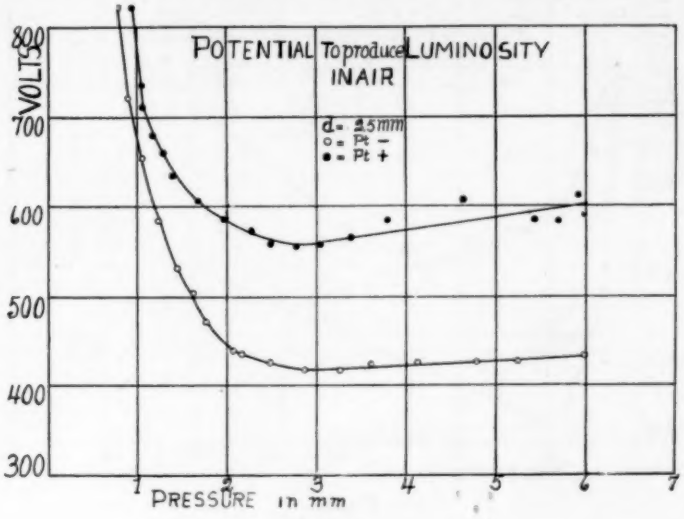

Fig. 4.

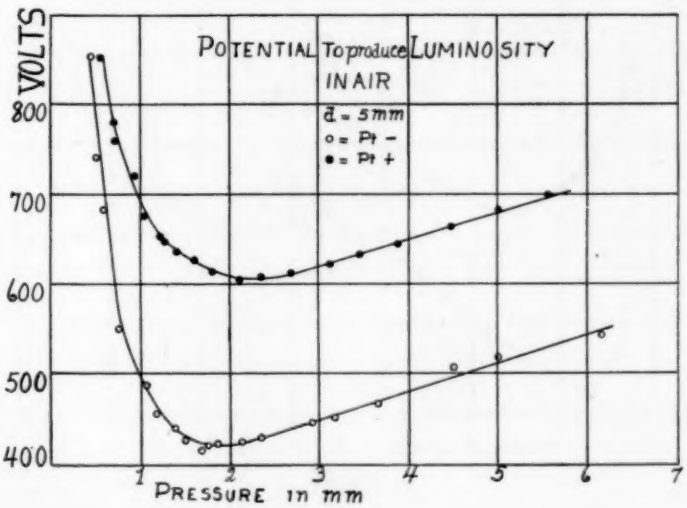

Fig. 5.

luminous discharge a small hole was bored in each of the washers employed to separate the electrodes so that the discharge could be

seen. However this precaution was not necessary, the kick of the voltmeter being sufficiently reliable.

Since the luminous discharge presupposes a supply of ions a dis-

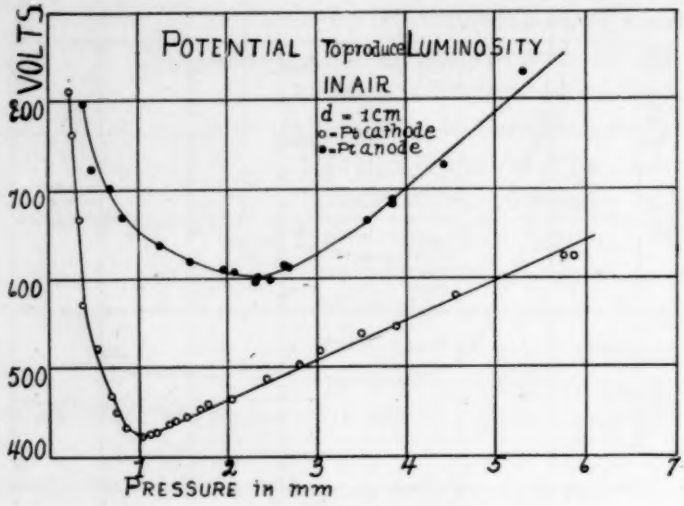

Fig. 6.

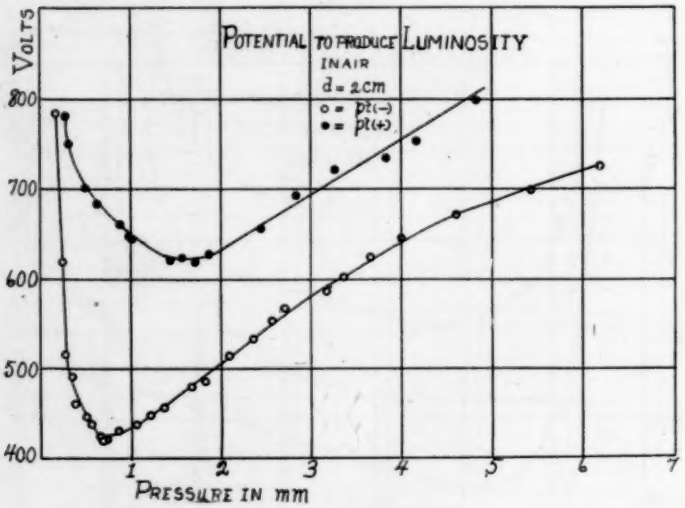

Fig. 7.

charge was produced to create them and then after several minutes the voltage was increased by small steps in the manner previously described until the discharge again passed. After each observa-

tion sufficient time was allowed to elapse for the gas to reach its normal condition before another reading was taken.

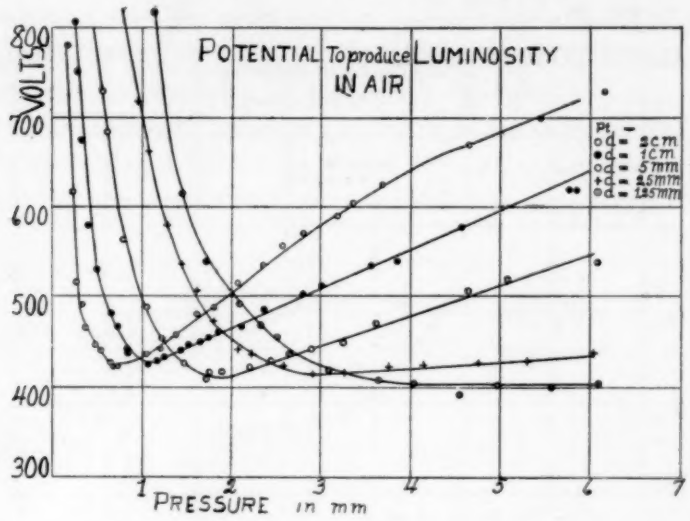

Fig. 8.

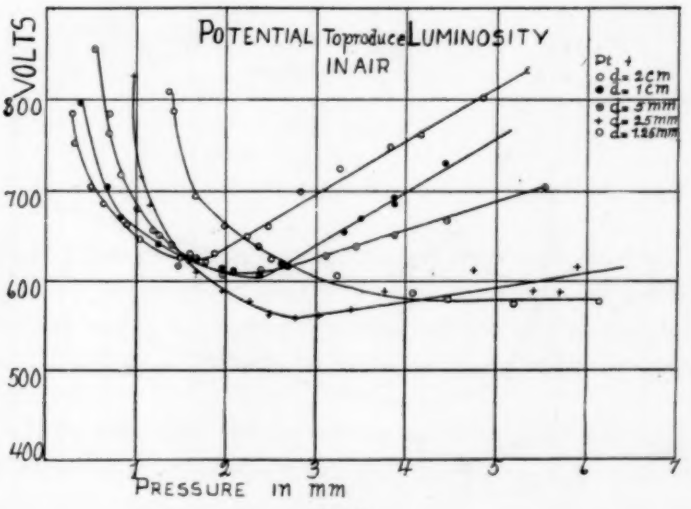

Fig. 9.

The delay in the passage of the discharge which has been noted by a number of investigators and carefully studied by Warburg[1]

[1] Warburg, Ann. der Phys., 62, p. 385.

was observed. As Carr[1] has noted, the lag was greater near the critical pressure. It was also greater below the critical pressure than above it.

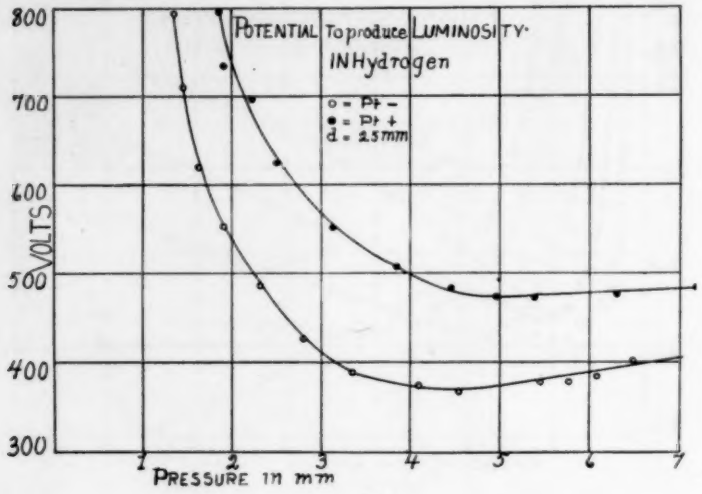

Fig. 10.

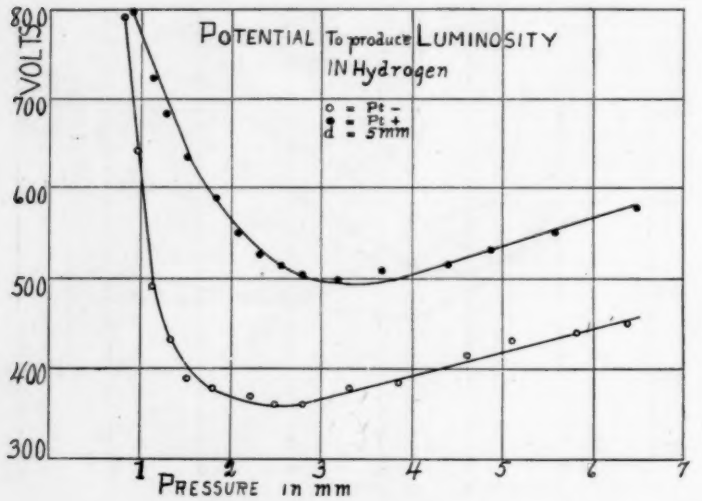

Fig. 11.

In beginning a series of readings in air the whole apparatus was exhausted to a pressure of about one millimeter of mercury and

[1] Carr, Phil. Trans. Roy. Soc., CCI., p. 403.

then refilled by allowing the air to pass in slowly through a tube packed with phosphoric pentoxide. The apparatus was then exhausted to a pressure of 10 mm. of mercury and allowed to stand over night, the air in the chamber being in constant contact with the phosphoric pentoxide in the drying chamber.

The measurements in the air were made at five different distances of the electrodes, 1.25, 2.5, 5, 10 and 20 mm., and extending over a range of pressure from 8 mm. to 0.27 mm. of mercury. The

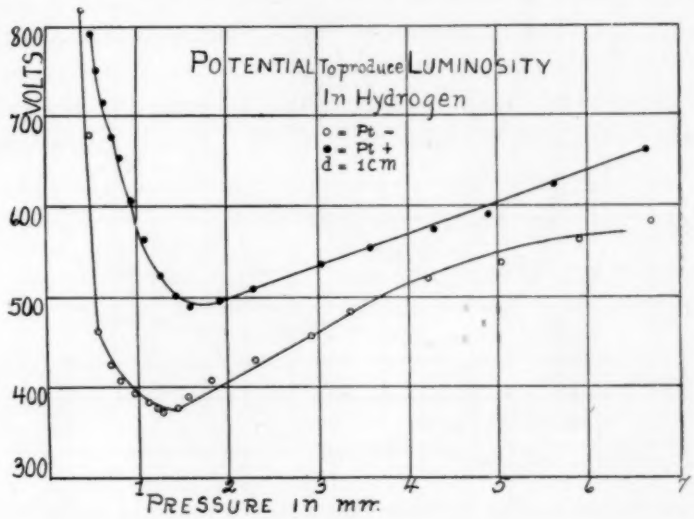

Fig. 12.

results of these measurements are shown graphically in Figs. 3, 4, 5, 6 and 7. Each curve shown is made from one continuous set of readings and is not a selection from several sets, although three series of readings were made for each distance and the average one was selected.

It will be seen that the curves for point negative are similar to those obtained by Carr and other experimenters for parallel plates, but with point positive the voltage required for a discharge at any certain pressure is higher than the voltage required at the corresponding pressure for point negative and the critical pressure for point positive is higher than for point negative. The potentials where rectification is possible obviously lie between the lines representing

the discharge for point positive and for point negative. Theoretically for an alternating potential within this region discharge would proceed only in one direction. It should be noted that within the limits of the experiment the most favorable region for this effect lies near the critical pressure and for the longer spark gap. For the purpose of comparison all the curves made with point negative

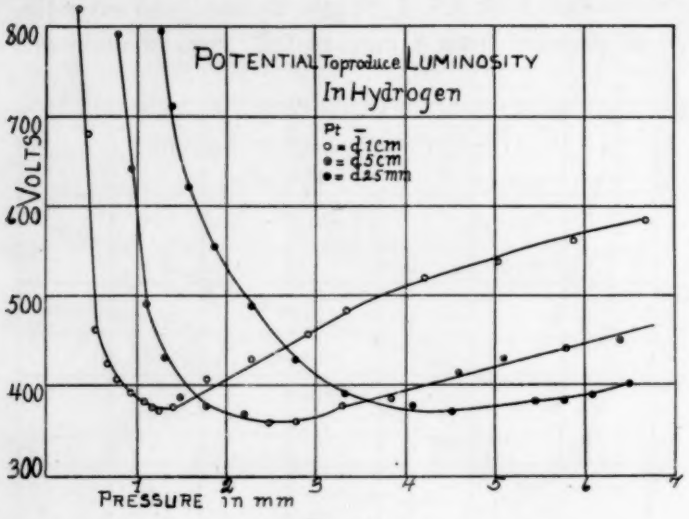

Fig. 13.

in air are shown in Fig. 8, while Fig. 9 shows a similar set of curves for point positive. Carr found the minimum potential required for a discharge between two parallel plates to be independent of the distance which separated them. In general the potential required for discharge depended only on the mass of gas between the electrodes, that is, Paschen's Law. In the case of discharge between parallel plates the entire mass of gas without doubt is affected. In the case of a point and a plane it is quite improbable that the entire quantity of gas within the chamber functions when the discharge takes place. Our lack of knowledge on the distribution of the discharge from a pointed conductor renders it impossible to say just what portion of the gas within the chamber functions; however it is not improbable that Paschen's Law holds in this case also. The minimum potentials as shown on the different curves are somewhat more consistent for point negative than for point positive. The

critical pressure varies with the distance of the electrodes in every case, but for any certain separation of the electrodes the critical pressure for the negatively electrified point is less than when the point is electrified positively.

In order to further test the laws governing such discharges it seemed advisable to carry out the experiment using another gas. Figs. 10, 11, 12, 13 and 14 show graphically the results obtained with hydrogen. The apparatus used was the same as in the experiments with air. The hydrogen was prepared in a Kipp apparatus by the action of sulphuric acid on chemically pure zinc and after passing through solutions of potassium permanganate and pyrogallic acid was dried by being passed through tubes packed with phosphoric pentoxide. While in this way absolutely pure hydrogen

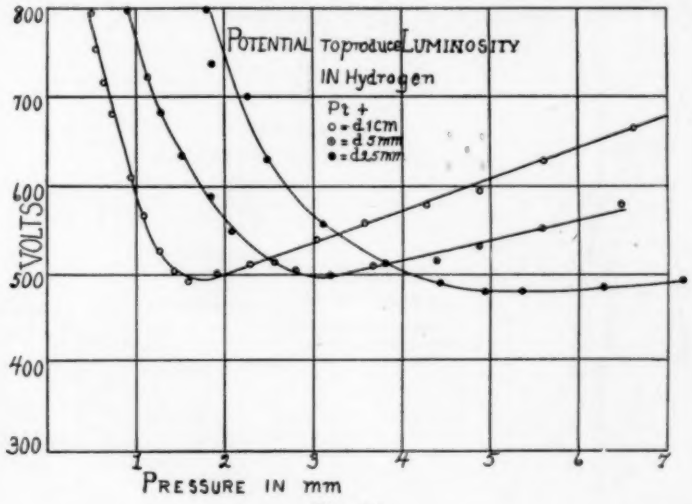

Fig. 14.

cannot be procured it is thought that the small amount of impurity did not seriously affect the results.

Before making the measurements with hydrogen the apparatus was exhausted of air to a pressure of about .5 mm. of mercury and then filled with hydrogen to atmospheric pressure. It was then exhausted and refilled four times to make certain that all air was removed after which the gas was allowed to stand for several hours in contact with phosphor pentoxide at a pressure of about 10 mm. of mercury before any readings were attempted.

The results obtained for hydrogen are quite similar to those obtained in air. The differences being just such differences as would be expected; the minimum potential required for the discharge being considerably less than for air and occurring at higher pressures.

These experiments have suggested several phases of this problem and it is hoped to make some considerable extension of it in the near future.

PHYSICAL LABORATORY,
OHIO STATE UNIVERSITY, COLUMBUS, OHIO.

AN APPARATUS FOR MEASURING SOUND.

By F. R. Watson.

THE apparatus which is described here was devised to measure quantitatively the intensity of sound in auditoriums. It was desired to have the instrument that received the sound impression both portable and easily adjusted. The apparatus which was developed to fulfill these conditions consists essentially of a telephone receiver connected in series with a thermo-galvanometer. Feeble sounds were augmented by altering the apparatus so as to make it resonant. Thus the source of sound was adjusted until a maxi-

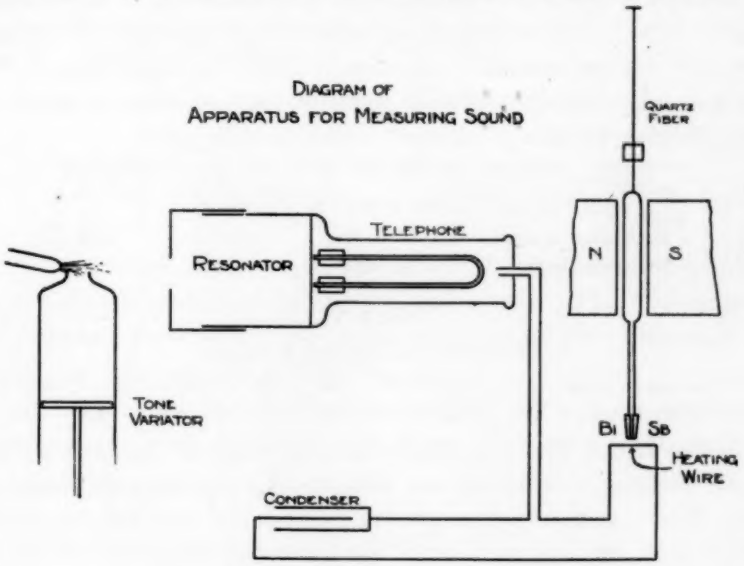

Fig. 1.

mum deflection of the galvanometer was obtained. A resonator was then mounted on the telephone plate and adjusted to give a second maximum deflection. The electric circuit was also tuned by inserting a condenser and altering the capacity to get a third maximum. Finally, the distance between the telephone plate and

the telephone magnet was adjusted for the greatest effect. Fig. 1 shows diagrammatically the apparatus used.

The Duddell thermo-galvanometer[1] used was found especially suited for this work, as it gave a steady deflection for the alternating currents set up by the telephone. Some idea of magnitude of the current used is given in the following data. Seventy microamperes caused a deflection of one centimeter when the scale was 100 cm. from the galvanometer. A current of 350 microamperes gave 25 cm. It is thus seen that the deflection varies as the *square* of the current; a fact that should be held in mind in making the apparatus sensitive. Thus an increase in the intensity of the source of sound magnifies the deflection of the galvanometer according to the square.

A tone variator was used as the source of sound. It consists of a hollow brass cylinder open at the top and closed at the bottom by an adjustable piston. The telephone receiver is one of an ordinary bipolar type. The resonator is a hollow brass cylinder, the adjustable cap fitting smoothly and closely over the base piece. The effect of adjusting the different parts of the apparatus is shown in the following tables.

TABLE I.

Effect of Heaters of Different Resistances.

Resistance in ohms,	94.8	47.3	3.68
Deflection in cm.,	9.0	4.0	0.5

TABLE II.

Effect of Resistance added in Circuit.

Resistance in ohms,	0.0	1.0	5	20	40	100	200	300
Deflection in cm.,	11.0	11.0	11+	10	9+	6.5	4.5	3+

Tables I. and II. show that the best effect is obtained with a heater resistance of about 100 ohms in the thermo-galvanometer.

TABLE III.

Effect of Varying Pitch of Source of Sound.

Pitch,	500	600	650	660	670	680	690	700	710	750	770
Deflection,	.4	1.3	3.3	3.9	4.6	5.7	6.2	7	7—	6.7	5.6

It is seen that the maximum deflection is reached for a pitch of 700 vibrations. To augment the effect, a wooden organ pipe giving a more intense sound was used as the source of sound. It was first tuned in unison with the tone variator.

[1] W. Duddell, Phil. Mag., 8, 91, 1904.

TABLE IV.

Effect of a More Intense Source of Sound.

Source of Sound.	Distance from Telephone.	Deflection.
Tone variator,	2 cm.	7 cm.
Organ pipe,	2 cm.	off scale
Organ pipe,	5 cm.	10 cm.

TABLE V.

Effect of Inserting Capacity in the Telephone Circuit.

Capacity,	0	.2	.4	.7	.9	1.0	1.2	1.5	1.7
Deflection,	10	1.7	6.4	13	14.5	15	14.5	14	13.3

The maximum deflection occurs for a capacity of one microfarad. To get a still greater effect, a resonator was then screwed over the telephone plate.

TABLE VI.

Effect of Resonator.

Instrument.	Distance from Horn.	Deflection.
Telephone without resonator,	10 cm.	0.5 cm.
Telephone with resonator,	10 cm.	off scale

TABLE VII.

Effect of Different Telephone Plates.

Diameter.	Thickness.	Distance from Horn.	Deflection.
5.3 cm.	.0335 cm.	15 cm.	4.8 cm.
5.2 cm.	.0195 cm.	20 cm.	20.0 cm.

The increased effect noted in Table VII. was probably not due to the difference in the thickness of the plates. The thinner plate was drawn closer to the telephone magnet and thus increased the magnetic field and the induced currents.

The apparatus was finally assembled as follows: An organ pipe having a pitch of about 700 vibrations a second was blown by a constant air pressure. The sound was received by a telephone receiver, having a plate 5.2 cm. in diameter and .0205 cm. thick. The brass resonator on the telephone plate was 4.9 cm. long, 5 cm. diameter, with a circular aperture 1.9 cm. in diameter. The telephone was connected in series with a condenser of one microfarad capacity, and with a thermo-galvanometer having a heating wire of 94.8 ohms resistance. Maxima and minima of sound were easily detected in a small laboratory. The apparatus gives quantitative measurements that may be repeated.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS.

SOME ELECTRICAL PROPERTIES OF SELENIUM.

BY LOUISE S. MCDOWELL.

II. THE RECOVERY FROM EXCITATION BY X-RAYS.

SINCE the experiments of Pfund[1] and Berndt[2] have conclusively disproved the theory of Bidwell that the increased conductivity of selenium under the action of light is due to the formation of conducting selenides, the most commonly accepted theory has been that of "allotropic dissociation," first proposed by Siemens.[3] According to the present form of the theory the effect of heat is to change the selenium from the amorphous to the crystalline form and further to a second crystalline form which alone is conducting. Following the notation of Schrott and Marc we may call the non-conducting crystalline form A and the conducting, B. Sensitive selenium consists of a solid solution of B in A. According to Marc[4] the effect of light is merely to alter the equilibrium in favor of B, but according to Hesehus[5] and Schrott[6] the effect of light is to dissociate the B dissolved in A, thus producing free ions which in the dark recombine. It is the latter form of the theory which we shall consider.

In an earlier paper the writer described some experiments dealing with the rate of recovery of the normal resistance of a selenium cell after exposure to light. When the recovery curves were plotted with the reciprocal square roots of the changes in conductivity as ordinates and the times as abscissæ, the form of the curves was found to be exactly similar to the curves obtained by Nichols and Merritt[7] for the decay of phosphorescence. Their method of plot-

[1] A. H. Pfund, Phil. Mag., Vol. 7, p. 26, 1904.
[2] G. W. Berndt, Phys. Zeit., Vol. 5, p. 121.
[3] Siemens, Phil. Mag., Vol. 50, p. 416.
[4] R. Marc, Zeit. für Anorgan. Chem., Vol. 50, p. 446, Vol. 53, p. 298.
[5] N. A. Hesehus, Phys. Zeit., Vol. 7, p. 163.
[6] Schrott, Akad. Wiss. Wien, Sitzungsber., Vol. 115, 2a, p. 1081.
[7] Nichols and Merritt, PHYS. REV., Vol. 22, p. 279, 1906.

ting rested upon the assumption that the intensity of phosphorescence is proportional to the number of recombinations per second. The hypothesis of Rutherford[1] that the number of recombinations is proportional to the number of collisions and hence to the number of positive and of negative ions leads to the relation $I = k\alpha n^2 = k\alpha/(1/n_0 + \alpha t)^2$, where n equals the number of positive (or negative) ions present per c.c. at any time t. This expression may be written in the form $1/\sqrt{I} = a + bt$, which indicates a linear relation between $I^{-\frac{1}{2}}$ and t. Experiments showed the curve to consist of three parts—a straight line for the early portion of the decay, a second part nearly straight but of radically different slope and bending somewhat towards the axis of abscissæ, the two connected by a sharp curve.

Merritt[2] has shown that this deviation from the straight line form indicated by the simple theory may be accounted for by an irregular distribution of the active substance, by diffusion, or by ionic grouping, and that any one of these factors is sufficient to explain the form of the curve. Since the recovery curves for selenium are of exactly the same form as the decay curves for phosphorescence, it seemed worth while to determine what part, if any, diffusion plays in determining the form of the curve. Selenium in the sensitive form is known to be almost entirely opaque to light,[3] so that any increase in the number of free ions in the interior must be due to diffusion from the surface layers. On the contrary, selenium is relatively transparent to X-rays. If diffusion is an important factor in determining the bend towards the axis of abscissæ, the recovery curves for X-ray excitation should approach more nearly the straight line form.

The cells used were four in number, all of the Bidwell type: cell *A*, the Max Kohl cell previously used, with a dark resistance of approximately 400,000 ohms; cell III., a home-made cell several months old, the dark resistance of which had risen gradually to approximately 450,000 ohms, cells XIV. and XX., two home-made cells with resistances, respectively, of 70,000 and 180,000 ohms.

[1] Rutherford, Phil. Mag., Vol. 44, p. 422.
[2] Merritt, PHYS. REV., Vol. 27, p. 367, 1908.
[3] Pfund, Phys. Zeit., Vol. 10, p. 340, 1909.

The cells were tested with the fluoroscope and found to be only partially transparent so that the spaces between the wires were but faintly discernible. When the hand was held behind the cell the shadow of the cell was roughly half that of the bones of the hand, whereas the mica form cast but a slight shadow.

The arrangement of apparatus was as follows:

The X-ray tube was placed about 12 cm. above the cell, enclosed in black paper. No precautions were taken to insure constancy of temperature or to eliminate moisture both because neither factor seemed to exert any noticeable disturbing influence and because the short duration of the experiments insured reasonable constancy of conditions. As a current source a single storage cell was used.

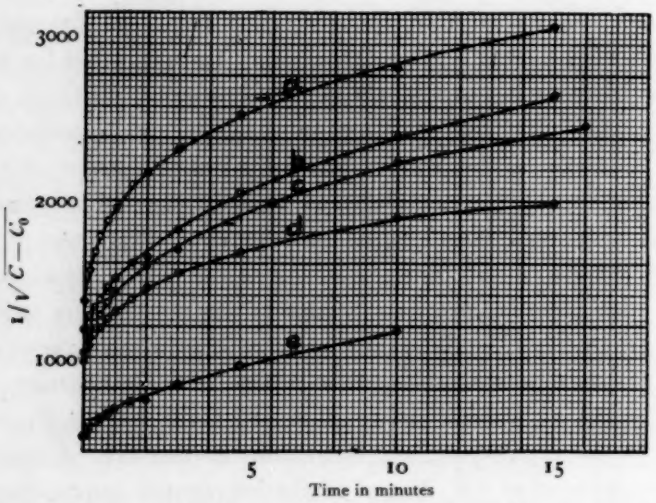

Fig. 1. Recovery after a two-minute excitation by X-rays. *a*, Cell III., initial dark resistance, 472,000; *b*, Cell XX., 181,500; *c*, Cell III., 446,000; *d*, Cell *A*, 414,000; *e*, Cell XIV., 70,000.

The resistance was measured, as in the earlier experiments, by making the cell one arm of a Wheatstone bridge, balanced for a known resistance approximately equal to that of the cell, and calibrated by the substitution for the cell of known resistances. Deflections were read by means of a beam of light reflected from the galvanometer mirror to a graduated scale. The galvanometer used was

a Sullivan galvanometer with a straight suspension to give an extremely short period. The method followed was to excite the cell to saturation, a process requiring approximately two minutes, then to shut off the X-rays and at short intervals during the recovery to note the resistance of the cell.

The curves were found to be exactly similar in form to the curves for recovery from light (see Figs. 1 and 2). No lessening of the bend towards the axis of abscissæ was perceptible. Hence it seems reasonable to conclude that the deviation from the straight line form is not to be explained by diffusion of ions from the surface layer.

No saturation curves were taken for the reason that the X-rays

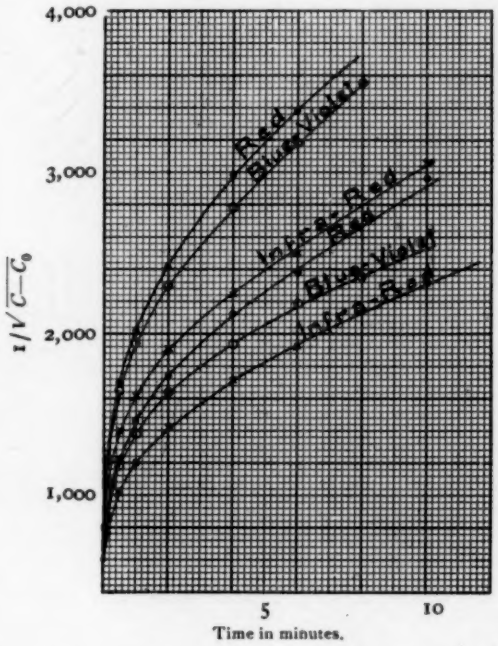

Fig. 2. Variation in rate of recovery with change in wave-length of light. Cell *A*.

were not sufficiently constant. During the earlier part of the two minutes they increased somewhat in intensity and towards the end sometimes diminished slightly because of the increased resistance of the tube, indicated by a sparking across the air gap and a faint lighting of the auxiliary tube. So far as could be judged, however, the saturation was approached somewhat more suddenly than in

the case of the light, with less of the long-continued, slight drifting of the galvanometer noticeable there.

While no special experiments were performed to compare the rate of recovery from excitation by light and by X-rays, a comparison of the curves of Figs. 1 and 2 shows that for cell *A* the recovery after a two-minute excitation by X-rays is much slower than after a five-second excitation by light even when the initial effect produced is the same. If it can be shown that the form of the recovery curve depends only upon the initial change in conductivity produced and not at all upon the time of excitation, then we may justly conclude that the rate of recovery from X-ray excitation is slower than

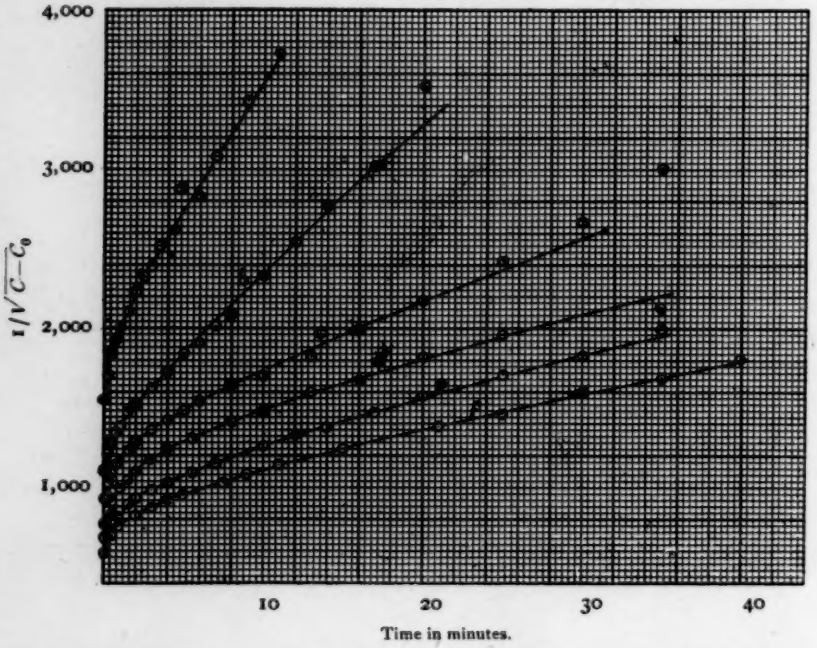

Fig. 3. Variation in the rate of recovery with intensity of excitation. Cell I. Twenty-second excitation by red light. Initial dark resistances: *a*, 53,920; *b*, 51,040; *c*, 51,800; *d*, 52,070; *e*, 55,160; *f*, 54,010.

from light. A study of the curves of Figs. 3 and 4, obtained in the earlier experiments, indicates a strong probability that such is the case. These curves were taken for the same cell and show the effect respectively of intensity and of time of excitation upon the

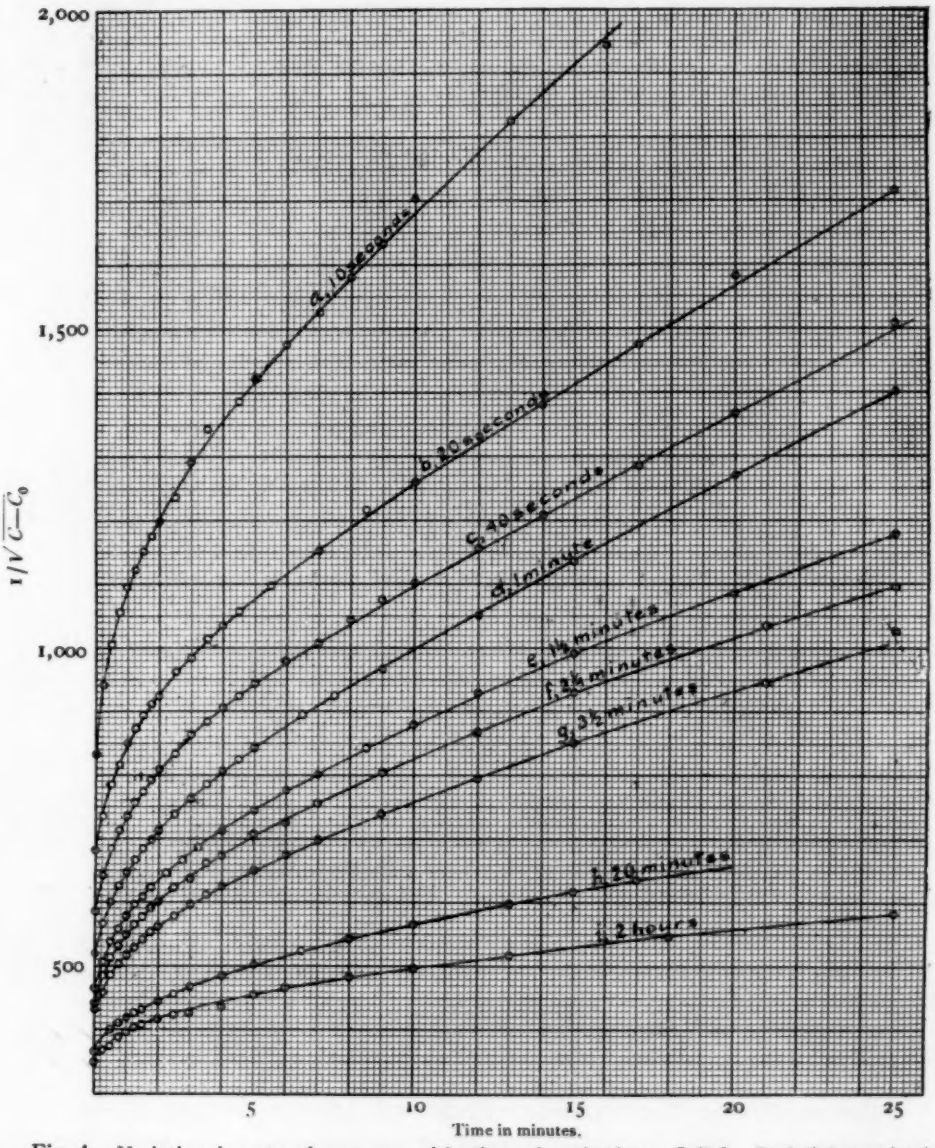

Fig. 4. Variation in rate of recovery with time of excitation. Cell I. Red light excitation. Initial dark resistances: *a*, 49,760; *b*, 55,160; *c*, 52,810; *d*, 52,870; *e*, 52,350; *f*, 53,120; *g*, 52,380; *h*, 51,480; *i*, 52,200.

recovery curve. In Fig. 5 are placed together curve *f*, Fig. 3, and curve *c*, Fig. 4, which chance to have approximately the same initial ordinate. Although produced by excitations of twenty and forty seconds respectively, these curves very nearly coincide. On

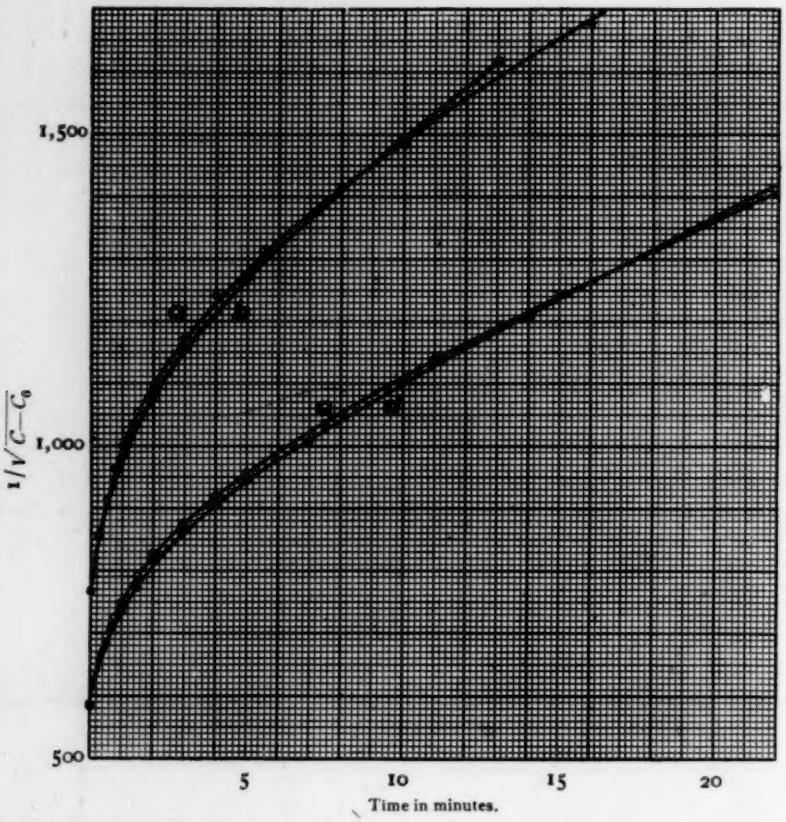

Fig. 5. Curves showing that the rate of recovery is independent of the time required to produce the initial change in conductivity. Cell *I*. *a*, Curve *d*, Fig. 3, time of excitation 20 seconds; *b*, derived curve intermediate between *a* and *b*, Fig. 4; *c*, curve *f*, Fig. 3, 20 seconds; d, curve *c*, Fig. 4, 40 seconds.

the assumption that time was without influence on the form of the curve there was calculated by means of auxiliary curves (for method see the earlier article[1]) the curve intermediate between *a* and *b*, Fig. 4, the initial ordinate of which was equal to that of curve *d*, Fig. 3. This derived curve was found to coincide approximately

[1] PHYS. REV., Vol. 29, p. 1.

with the curve experimentally determined. Although this evidence is hardly sufficient to be conclusive, it indicates a decided probability that the form of the curve is independent of the time required to produce the initial change of conductivity. This result in itself suggests that diffusion is not an important factor in determining the form of the curve. If it were, the longer excitation would be followed by a slower recovery, since in that case the ions would be diffused through a larger volume. The conclusion that the rate of recovery from X-ray excitation is slower than from light excitation is in exact agreement with the work of Perreau.[1]

The results of the investigation may be briefly summarized as follows:

1. The forms of the recovery curve for X-ray excitation and for light excitation are identical.

2. The form of the recovery curve for excitation by light depends only upon the magnitude of the initial change in conductivity and not at all upon the time required to produce that change.

3. The rate of recovery from excitation by X-rays is slower than from excitation by light.

4. Hence diffusion is probably not an mportant factor in producing the deviation from the straight line of the selenium recovery curves.

These experiments were carried on during the summer of 1909 in the Physics Laboratory of Cornell University, and in conclusion the writer wishes to express her gratitude to Professor Merritt at whose suggestion the work was undertaken.

PHYSICS LABORATORY,
WELLESLEY COLLEGE.

[1] M Perreau, Comptes Rendus, Vol. 129, p. 956.

TYPICAL CASES OF SECONDARY RADIATION EXCITED BY URANIUM-X.

BY W. B. HUFF.

AMONG recent papers dealing with the various aspects of secondary radiation, several describe in some detail the effects obtained by using Ur-X as the source of the primary. An extremely suggestive article by Bragg[1] calls attention to the errors introduced by using the usual ionization method of comparing radiations which are not only markedly different in intensity, but which have not produced the entire ionization each is capable of effecting.

A somewhat earlier paper by Schmidt[2] gives an account of his work with the secondary from the β- and γ-rays of Ur-X. In his experiments the radio-active material was placed just above the ionization chamber of an electroscope. The resulting effect was due, in the main, to the primary radiation. A metal plate was then placed directly over the Ur-X and the secondary radiation from this added its ionization to that produced by the primary. The method is therefore a differential one.

This increase of ionization due to the secondary from thick plates of various metals was found to follow the order of atomic weights. Schmidt also studied thin plates as reflectors and as absorbers.

The present investigation arose from some apparently quite anomalous results which were obtained during a study of the radiation from single crystals of uranium nitrate. During the earlier part of the work, a method was used which, as it happened, was essentially that of Schmidt, and a considerable part of his observations was verified. However, a further consideration of the experimental problem brought into sharper relief certain difficulties inherent in this method. The secondary radiations obtained may vary in ion-

[1] Phil. Mag., Oct., 1907.
[2] Ann. d. Phys., 23, 1907.

izing effect (as measured in a small chamber) from about 70 per cent. of the primary down to only a small fraction of this. Further, the secondary itself varies in intensity and amount with the reflecting substance, and may be absorbed by thin plates quite differently from the primary. It is also necessary to cut out the strongly ionizing α-rays, and about 0.10 mm. of aluminium foil must be used for this purpose. This shield not only modifies the radiations, but also adds to their ionizations an additional one due to their emergence from the aluminium.

It seemed desirable therefore to choose a method which would not necessitate such differential measurement, and which would allow a study of the secondary β-rays modified as little as possible by shielding.

Apparatus.

The plan finally adopted was to use the thinnest possible leaf of aluminium as the top of a small, cylindrical gold-leaf electroscope of very small capacity. The Ur-X was placed in a shallow circular groove in a brass plate nearly in the plane of the aluminium leaf and surrounding it. The thickness of plate and electroscope case was such that only the very penetrating γ-rays added their effect to the natural leak of the instrument.

The plate giving off the secondary to be studied was placed at a little distance above the Ur-X. Thus a considerable part of the secondary radiation from this plate passed down through the aluminium leaf into the electroscope.

The case of the electroscope used for most of the observations was of cylindrical brass tubing 4.7 cm. inside diameter and 14 cm. high, built up of accurately fitted sections so that the total height could be varied and the effect of the change of wall area noted. The insulation of gold-leaf and standard was of sulphur or of quartz. These were about equally good if the air within was kept dry. A sulphur condenser could be used to decrease the rate of leak. The aluminium leaf forming the top of the case was as nearly free from holes as possible and was held taut by a brass ring grooved to fit the vertical wall of the case. A circular area of the leaf 4 cm. in diameter was exposed to radiation from the reflecting plate. The case was closed and waxed, and the inside air kept dry with sulphuric acid at the bottom of the chamber.

The charging and reading were done in the usual manner, ten scale-divisions of the reading microscope corresponding to a movement of the gold-leaf through 1 mm. At 200 volts the natural leak, after standing and drying, was about three scale-divisions per hour. This varied somewhat from day to day as well as at different times of the day, but such variations could usually be taken into account in so far as they were important.

A second brass plate on top of the electroscope had a circular opening 4.2 cm. in diameter and concentric with the 4 cm. hole exposing the aluminium leaf, thus forming a shoulder for the support of discs used in studying absorption. Outside this 4.2 cm. hole and concentric with it was a circular groove, 1 mm. deep, 1 cm. wide and 5 cm. inside diameter, which contained the Ur-X. A slender brass tripod on this second ring supported the reflecting plate. Its height could be varied, thus varying the air-path and the angle of the secondary beam. The aluminium leaf was about 5 mm. below the Ur-X and was thus shielded from all direct radiation.

The reflectors were discs about 8 cm. in diameter and rested, polished face down, on the thin ring of the tripod. The latter insured a constant area of the reflector exposed to primary radiation and protected the edge of the disc. Most of the measurements were taken with the disc about 1 cm. from the Ur-X.

The Ur-X was prepared from the nitrate by the usual method of separating from an ether solution by water and then by successive rapid crystallizations and subsequent filtering through the oxide which formed on standing. The result was a fine, grayish powder which did not collect moisture when exposed to the atmosphere.

A very thin layer was distributed and kept as nearly uniform as possible over the bottom of the groove. Its absorption was neglected. The Ur-X was covered with 0.10 mm. of aluminium, waxed down to the edges of the groove. This cut out the α-rays and in some degree modified the penetrating radiation. Some observations taken without this screen will be noted later.

SOURCES OF ERROR.

It is obvious that the above arrangement does not give parallel secondary rays; nor are these completely absorbed in the air of the

ionizing chamber. As a result, the measurements may be affected by the walls of the electroscope. Yet any method of getting parallel rays by increasing distances, or by using a bundle of tubes or slits, would bring in either a very considerable air-absorption, or an increase of surface, either of which might seriously modify the radiation before it entered the ionizing chamber.

Except for very weak ionizations, variations in the rate of natural leak were not of great importance. It is a much more difficult matter to avoid disturbances of the gold-leaf by air-currents arising from temperature changes in the electroscope. Unless the case is carefully shielded, and readings taken only after the observer has been for some time at the microscope, such errors may reach 10 per cent.

In changing reflectors, especially when the ionizations are weak, a considerable time must be allowed for the ionization to become steady. The time taken for the gold-leaf to pass over 10 scale-divisions varied from 5 minutes to several hours. Except when the variation in the rate of natural leak became comparable with the ionization, a set of readings under given conditions usually agreed to well within 1 per cent. The effects from a thick plate of iron and one of nickel could be distinguished readily.

It is evident also that whatever shallow vessel contains the radio-active material, the secondary from the bottom will be added to the primary. Thus a lead vessel would add something like 70 per cent., much of this increase being very penetrating. Aluminium would add much less and the increase would be softer. In either case, the effect on the result from the reflecting plate may become considerable, especially in a study of the absorption of such superposed radiations by very thin plates.

There will also be what may be styled multiple-reflections between the top of the electroscope and the plate above it. These were judged to be small when electroscope and plate were not less than 1 cm. apart, since covering the exposed brass of the top of the electroscope with lead made little difference in the readings. But when reflecting plate and radio-active material are very close together, as in the differential method first used, it is possible that very penetrating rays may give higher order effects which would become important.

To study possible tertiary effects from the inner walls of the electroscope, a second instrument was constructed. Its case was 6.5 cm. high and 12 cm. in diameter. The bottom could be of thick brass, or of aluminium foil 0.01 mm. thick. The ratios of ionizations from various pairs of reflectors such as lead and aluminium, bismuth and magnesium, did not differ materially from values obtained by using the taller and narrower type of instrument.

Experiments.

The values of the ratio of the secondary from a thick plate of lead to that from one of aluminium was found to depend on the distance of the reflecting plate from the Ur-X, as shown by the following numbers.

Distance.	Ratio.
4.0 cm.	3.2
1.0 "	2.5
0.3 "	2.0

Difference in air-path and change in possible angles of incidence of the primary upon the plate as well as of the secondary upon the aluminium leaf, contribute to this variation.

Such results show at once the difficulty of doing more than arranging the elementary substances according to the ionization produced by their secondary radiation. Schmidt found that the order is that of atomic weights. This result was easily verified for fifteen elements, though the ratios for each element to some one of them differed considerably (and not all in the same direction) from those calculated from Schmidt's results. However, it may be added that S and As fall into place. Alloys of Cd and Bi containing but a few per cent. of one constituent were only slightly different from the pure metals as reflectors. Accordingly a sodium alloy of mercury was compared with bismuth. The result placed mercury roughly in the position which would be given by its atomic weight.

Using thick plates of lead and aluminium as typical examples of reflectors of high and low atomic weights, and a thick plate of tin as intermediate between these extremes, curves were obtained for the absorption of the secondary by thin plates, the same three metals being used as typical absorbers. Considerable variation was observed in different samples of lead foil. That finally used was

nearly pure. The reflecting tin plate was cast from pure tin. The absorbing tin leaf was marked pure and was of nearly uniform thickness. The aluminium was the commercial article.

To study absorption, circular discs of the foil were cut, fitting into the 4.2 cm. hole above the aluminium leaf. These discs were made as nearly plane as possible and lay almost in the plane of the Ur-X, to minimize γ-ray effects.

In the final reductions of readings, the decay of the Ur-X was taken into account. The ratio of the effect from lead to that from aluminium remained nearly constant throughout the time each sample was used.

Corrections for leak were also made, and for change of this leak due to decay of the Ur-X. Allowance was also made for the secon-

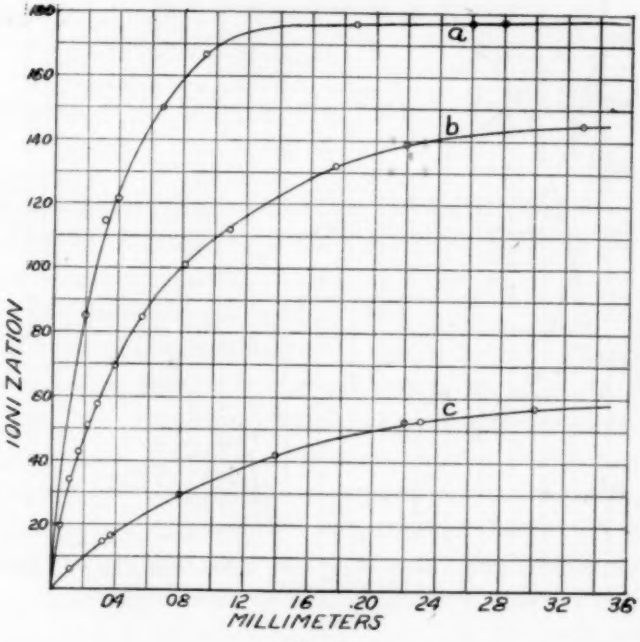

Fig. 1.

dary given off from the tripod. The effect of the tripod alone, *i. e.*, carrying no reflecting plate, was about equal to the natural leak.

The amount and character of the returned radiation depends also on the thickness of the reflecting discs. Comparison curves are given for the three metals used.

The curves for reflection and absorption are drawn with thicknesses of metal in hundredths of 1 mm. as abscissas, and ionization proportional to scale-divisions per minute as ordinates. The fact that the ratio of the ionization is nearly constant and independent of decay of the radio-active material was used in reducing the ordinates to a common scale.

Fig. 1 shows the increase of ionization arising from increase of secondary as the thickness of the reflecting metal plates above the Ur-X is increased. The curves for Pb, Sn and Al are shown by *a*, *b*, *c*, respectively.

In Fig. 2 the curves *a*, *b*, *c* show the absorption of the secondary from a thick plate of lead when it passes through Pb, Sn or Al.

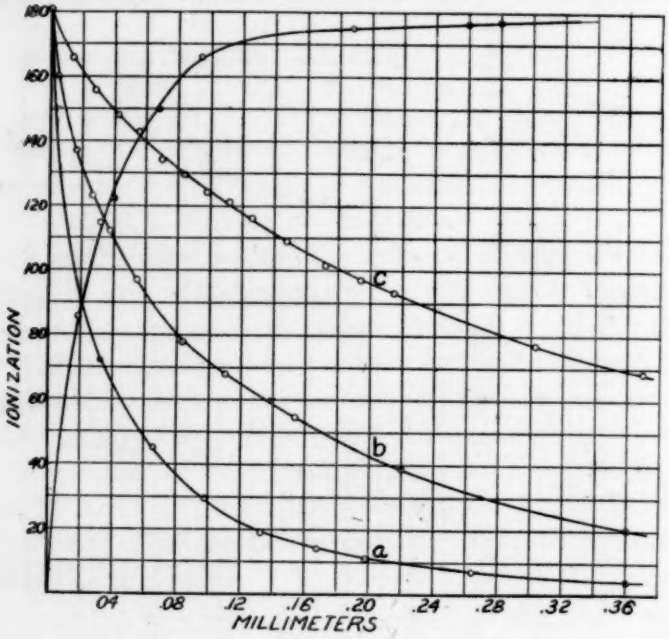

Fig. 2.

The curve *a*, Fig. 1, is given for comparison. Fig. 3 corresponds to Fig. 2, except that the secondary comes from aluminium.

Except for thin layers, the absorption by aluminium is almost linear, and continues so up to thicknesses of about 1 mm. The absorption by lead is more nearly exponential at first, but for both

lead and tin the effect becomes roughly linear for the more penetrating rays. Secondary γ radiation, since it would not be much affected by plates thick enough to absorb most of the secondary β-rays, would become of importance in studying absorption by any but comparatively thin sheets.

The reflection and absorption curves for lead and for aluminium cut at a point corresponding to about half the maximum ionization. Thus the ionization from a thick plate of each metal is reduced to

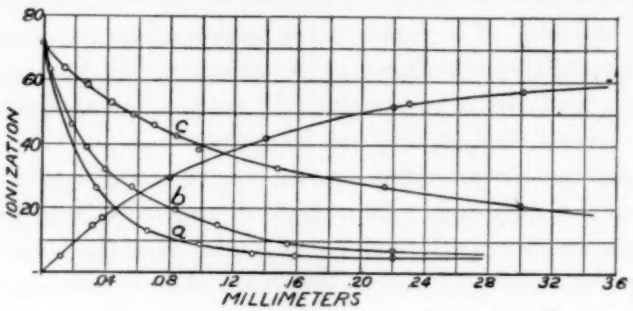

Fig. 3.

half value by an absorbing layer of the same metal which is approximately equal in thickness to a plate returning half the primary.

An attempt was also made to study the secondary radiation from extremely thin layers of gold and of aluminium. The effect of a single gold leaf could be detected easily, and each successive addition up to fifteen leaves gave an increase of ionization. The curve thus obtained was, however, more irregular than inequalities of distance between leaves and Ur-X, or than variations in the thickness of the leaves (obtained by weighing, measuring, and assuming the density) could account for. It was further noted that, with a steady electroscope and under almost the same weather conditions, measurements of ionization from the same group of leaves and made between the same hours of successive days gave decidedly smaller results; never larger ones. How far this may have been due to shutting the inner leaves partially away from the air remains to be determined. It is also probable that for such thin reflectors the results are complicated by secondary from the air above them.

The thinnest sheet of lead which could be got gave a large per-

centage of the effect obtainable from a thick plate. Therefore the first part of the reflection curve typical of elements of high atomic weight cannot be said to be based on accurate data. But it may be said that the addition of successive small thicknesses to a very thin reflecting layer increases the ionization fairly regularly.

It was conceivable that the reflected radiations from metals of nearly the same atomic weights might be differently absorbed by plates of the same material as one of the reflectors. Various combinations were tried, including Pb and Bi, Zn and Cu, Fe and Ni, and Al and Mg. The ratios of ionizations produced after partial absorption of the secondary by discs of various thicknesses did not differ markedly from those calculated for ionization when the secondary passed through only the aluminium leaf.

Throughout the preceding experiments the Ur-X was covered so as to cut out the α-rays. This shield of course modified the radiation passing through it and consequently also the return radiation from the reflecting plate. With each plate at the same distance from the Ur-X, the ratio for lead to aluminium with the shield was 2.54; without it, 2.39. Curves were drawn showing the absorption by aluminium of the secondary from lead and from aluminium, the Ur-X being uncovered. The curve for lead was fairly normal until the secondary radiation had passed through about 0.08 mm. of the foil. Then there was a sudden decrease in the ionization, the curve afterward becoming normal again. A similar discontinuity, though much less marked, was observed in the curve for the secondary from aluminium when this passed through about 0.04 mm. of aluminium foil. Such sudden changes in the absorption curves may be accounted for by scattered α-rays, or by a soft and fairly homogeneous secondary due to them.

In conclusion it may be said that the experimental results of this direct method of comparing the secondary radiations are in agreement with Schmidt's statement that the intensities of secondary radiation excited by β-rays of Ur-X are in the order of atomic weights for elementary substances. Although the order seems to be definite, the total ionization effects vary greatly with the arrangement of apparatus.

The reflection and absorption seem not to follow any simple law.

The curves bring out clearly characteristic differences for three typical elements when acting as reflectors and as absorbers.

Nothing in the nature of selective absorption was detected. This may be held to indicate that the secondary is largely returned or scattered primary, rather than independent, though characteristic, radiation emitted merely as a result of incident primary.

Questions as to the reflection from extremely thin plates, and as to the absorption of radiation from plates so thin as to give only a part of the total secondary which may be obtained from thick plates, are at present under examination.

PHYSICAL LABORATORY,
BRYN MAWR COLLEGE.

AN AUTOMATIC CIRCULAR DIVIDING ENGINE.

BY W. R. STAMPER.

WITH CALIBRATION OF THE WORM AND GEAR.

BY ELMER E. HALL.

HAVING felt the need of a reliable circular dividing engine, the department of physics of the University of California decided, some five years ago, to build such an instrument and it devolved upon the writer as mechanician in the department of physics to design and build the instrument. Being unable to get any literature on the subject of dividing engines either from libraries or from factories, after having constructed one of my own peculiar design I have decided to publish an account of its construction in detail, with drawings and photographs, so that those interested may derive some benefit, if possible, from my experience.

The gear wheel *A* (see sectional drawing, Fig. 1) weighs 150 pounds and was made by the Brown and Sharpe Manufacturing Co., of Providence, Rhode Island. The wheel is made of soft cast iron, suitably braced and designed. It is 24 inches in diameter, 1 ¼ inches thick at the teeth, with a taper hole in the hub. The hub is 4 inches long, with a two-inch hole through it, the taper being one half inch per foot. This hole is not the running bearing, the gear wheel being made rigid to the main spindle *D*, by means of the nut *B*, which is threaded on the top of the spindle. On the top face of the gear, near the edge, there is a rough, coarse scale cut in the cast iron and divided into degrees for convenience in starting, rough dividing and calibration. There are 360 teeth in the gear wheel, thus dividing the wheel into degrees, the teeth being of standard worm pitch.

The main spindle *D* is a piece of box-annealed machinery steel and was well seasoned before the final finishing was done. The spindle has a taper hole extending all the way through, which receives the taper spindle *J*, upon which all work to be divided is

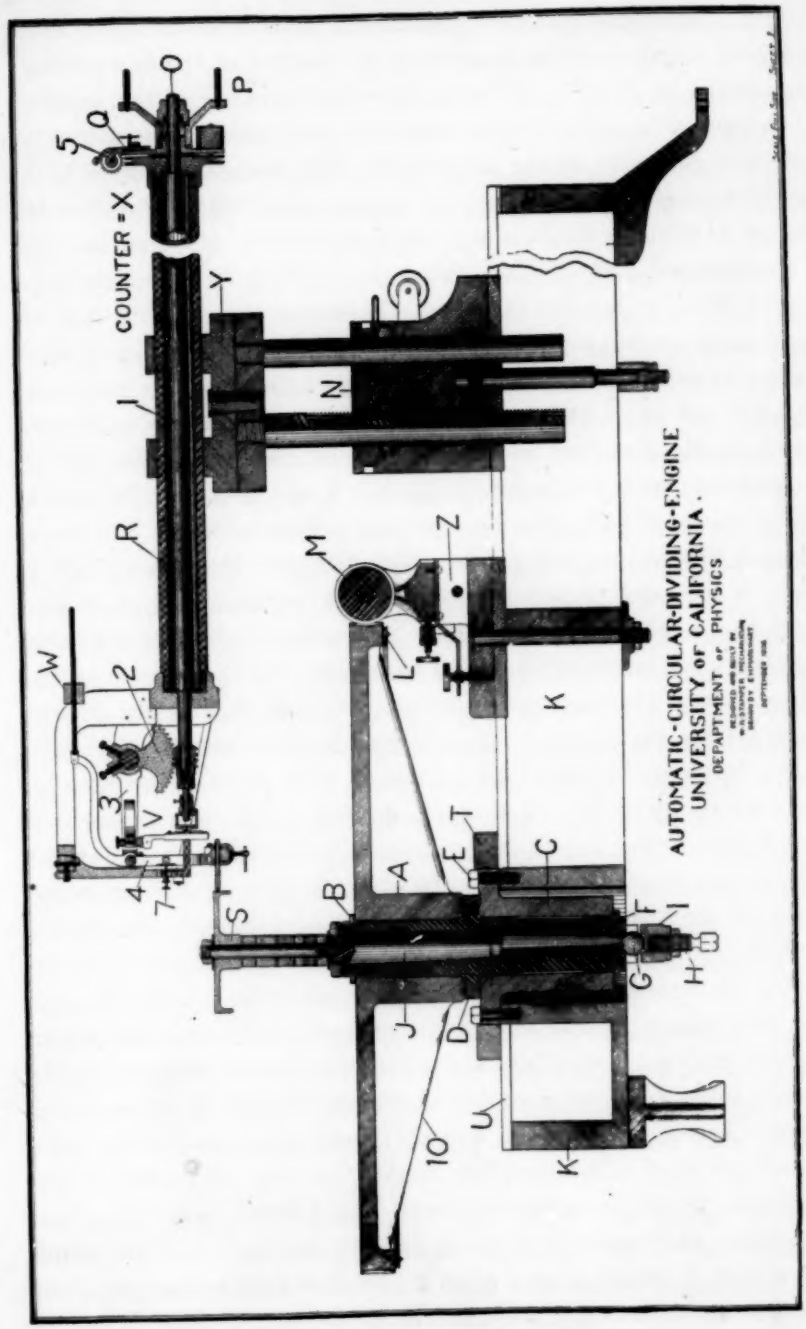
AUTOMATIC-CIRCULAR-DIVIDING-ENGINE
UNIVERSITY of CALIFORNIA.
DEPARTMENT of PHYSICS
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Fig. 1.

placed. This taper hole is 1¼ inches in diameter at the upper end and three fourths inch in diameter at the lower end, the taper being five eighths of an inch per foot. The main bearing of the spindle has a taper of one half inch per foot and is 5 inches long and 2½ inches in diameter at the large end. The spindle revolves in a cast-iron collar or bearing *C*, which was also treated so as not to change its form in the future. The flange of the collar or bearing *C* was scraped and carefully fitted on the bed *K* before the cap screws *EE* were screwed in place. I consider this bearing one of the most essential parts of the dividing engine, and I was extremely careful to secure a good fit. The lapping of the taper hole was done with the aid of Arkansas stone dust. The Arkansas stone dust, being readily dissolved in benzine, can be easily and thoroughly cleaned out when the abrasion is done. I am using the best watch oil for the lubrication, it being light and not gummy. A critic may say that this bearing should be much longer. Perhaps so, but I doubt if it would be any improvement in accuracy, provided the short bearing is accurately made. However, if the scope of the machinery had permitted, I would have made the bearing somewhat longer, but on the same general plan. To take the weight off the bearing I use, instead of the double-ended male center used by most of the factories, the one inch hardened steel ball *G*. If there be any eccentricity in the rotation, the double-ended male center rod would have a tendency to raise the gear, while the steel ball would not, there being a hardened surface on the end of the adjusting screw *H*, for the ball to rest on. This is, I believe, the better method.

The adjustment of the bearing is made, assuming that the bearing is in its working position free from dust and oiled with good watch oil, by applying a spring balance to the periphery of the gear wheel. I find it takes a pull of from five to six pounds weight to start the wheel. I then screw up the screw *H* until about 149 of the 150 pounds are lifted, allowing a free running bearing with a film of oil about one ten-thousandth of an inch thick, which is sufficient for lubricating and retaining a good working bearing. I then found that it took a pull of about 1½ to 2 pounds weight to start the gear wheel. After starting, it took practically nothing to keep it going.

However in actual work the intervals during which the wheel is moving are so short that it is only the starting torque that is important. Therefore the weight must be taken off the taper bearing in order that there may not be too much strain on the worm in driving the gear wheel, for much strain would mean inaccuracy. An added load of 145 pounds placed on the gear wheel did not appreciably change the pull required to start the wheel.

At first I applied what I called a balancing device, consisting of a cord which passed around the sheave *L*, underneath the gear wheel, and then to a pulley on the wall, from which it passed over a second pulley on the ceiling, extending downward to receive a weight nearly sufficient to supply the starting force of two pounds. It was found that this balancing device rendered the engine too sensitive to dust, and the unequal distribution of oil on the gear made the readings vary from 10 to 15 seconds. The tangential pull of two pounds which must be supplied by the worm seems to be better than reducing this pull by balancing, provided the friction head *O*, on the worm shaft, remains constant in its rotation.

The worm and shaft *M* were also made by the Brown and Sharpe Manufacturing Co., to the same degree of accuracy as the gear, and are mounted on a suitable bearing or support, *Z*. It has a thrust bearing, stops, and all required adjustments, and is provided with rachet and automatic friction head not shown in Fig. 1. In addition to the friction head on the driving shaft of the worm there is a second friction head *O*, shown in Fig. 3, on the shaft *P*, controlling the cutting device. These friction heads have wooden surfaces, endwise of the grain, rubbing against cast iron. The greatest care possible was taken to get constant friction. The wood used was teak, which furnishes its own lubrication, it being naturally an oily wood. The wear is taken up by a spiral spring as shown in the figure. The two friction heads are run from the same source, one friction head waiting while the other catches up, and vice versa.

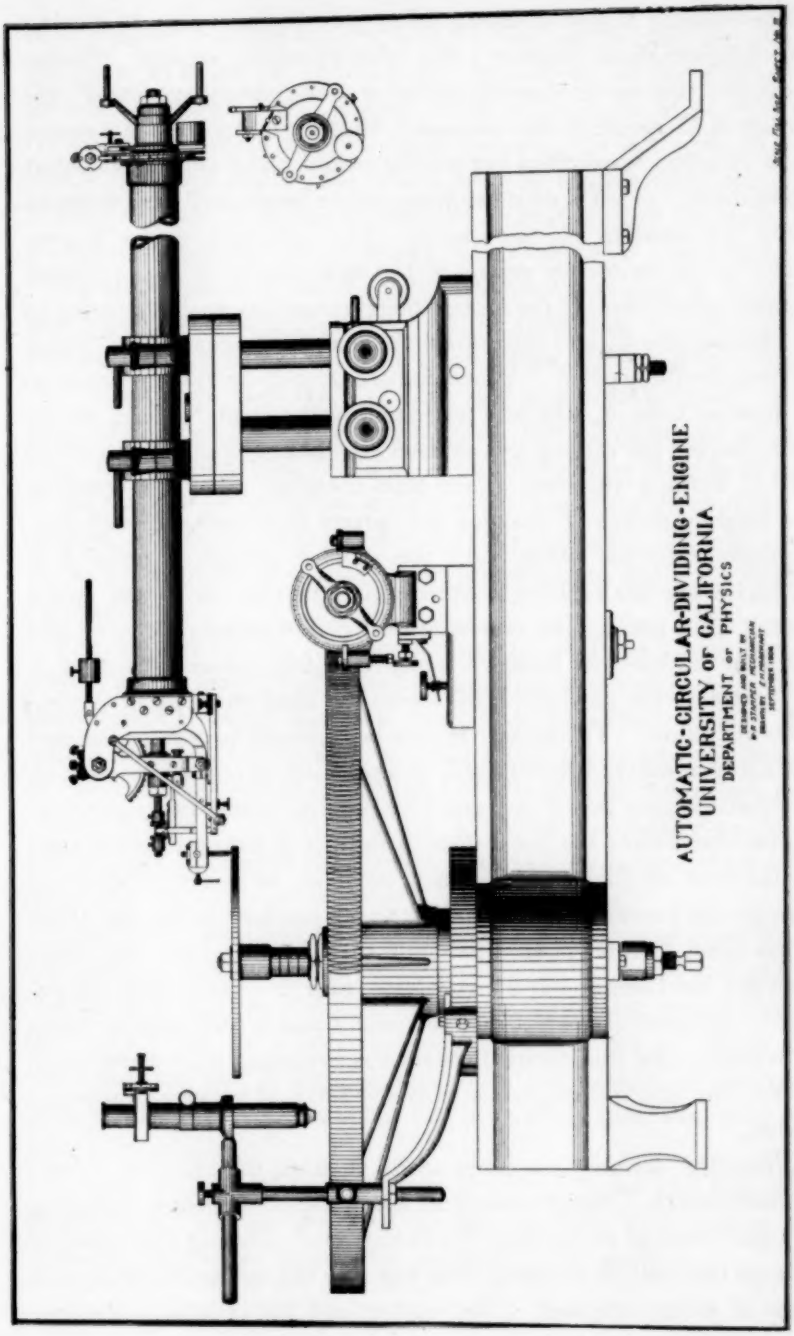
The tail stock *N*, Fig. 1, is movable either way along the bed *K*, and is provided with tighteners similar to the ordinary lathe. The support *Y* is provided with a rack and pinion adjustment, by means of which it is adjustable up and down to suit the class of

work. There are also tighteners provided to keep it in the required position after it has been moved. The hollow steel shaft *R* passes through the support *Y* and is also provided with tighteners, so that by the adjustments of the tail stock it is possible to divide a circle of any size up to five and one half feet in diameter. *X*, *8* and *10* show the positions, respectively, of the counter, stop and vibration support seen in Fig. 5.

The marking head *V*, which is rigidly attached to the end of the hollow shaft *R*, is operated by means of the shaft *1*, and by the rotation of the friction head which also propells the part *Q*. The slotted disc, shown in Fig. 2, on the piece *Q* strikes against stops placed at the required distance apart. On the piece *P*, Fig. 1, there are three stops, as seen in Fig. 2, long, medium and short. When a long line is made, the piece *Q* will rotate and allow the deep slot in the slotted disc to pass over the two shorter stops and stop at the longer one. Part *Q* is then rotated back until the star or escapement wheel *5* strikes a hook or stop, shown in Fig. 2, which rotates disc *5* one tooth, and also rotates the slotted disc, so that when *Q* is again rotated toward the stop it strikes a section of the slotted disc where there is no slot, and therefore makes a short line. This operation is continued, enabling one to produce graduations with any required lengths of lines.

The worm *9* is keyed to the shaft *1*, so that when shaft *1* is rotated, it rotates gear segment *2*, moving the arm *3*, lifting the part *4*, and thereby causing the knife or cutter *6* either to cut or return upon the periphery of the wheel *S*. The counterpoise *W* is adjustable so as to make the line as fine as desired. The screw *7* provides adjustment of the knife up or down.

The cutting head *V* is provided with cams, screws, lifts and all necessary adjustments, as may be seen from the several figures. In Fig. 1 the head is set to divide the periphery of the wheel *S*. In Fig 2 it is set to divide the top surface near the edge as an ordinary spectrometer scale is divided. It can be seen from the drawings that there are only a few parts to be interchanged in shifting from the top surface to the periphery, or the reverse. This head may seem complicated, but a study of the drawings will show that it is extremely simple.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DEPARTMENT OF PHYSICS

Fig. 2.

The dividing engine is driven by a ½-H.P. 104-volt self-starting A.C. Wagner motor, making 1,800 revolutions per minute. Owing to the fact that we were unable to get a slow running automatic self-starting A.C. motor it was necessary to gear down so that a motor speed of 1,800 revolutions per minute would make one line in about two seconds. That is why the apparently complicated device shown in Fig. 3 is used to run the engine. This automatic device is propelled by the motor by means of the steel worm *A*, Fig. 3, which engages worm wheel *B*, the motion being communicated by gearing to the change gear *C*, and then down the shaft to the gear box *J*, which is driven by the pawl *F*. When the arm *E* is in an upward position, the tapered cone *V*, which is feathered on the shaft *P*, slides downward forcing the driving arm or pawl *F* to be engaged in the toothed head *G*, turning the shell *J*, and also the shaft *P*, as *F* is rotating The rotating switch *W* changes the current from one of the electromagnets *D* to the other. As the pawl *F* rotates, a position is reached when the rotating switch shifts the current to the lower magnet, thus pulling the reversing arm *E* downward, engaging the arm *I* in the toothed band *H*, which is rigidly around the shell *J*, and releasing the pawl *F*. This forces the shaft to rotate in the opposite direction. The switch *W* can be changed to reverse the motion at any number of revolutions, or a part of a revolution, as desired. The shell or gear box *J* contains four bevelled gears, two tight ones and two loose ones, the loose ones being in a horizontal position and not fastened to their shaft. They only act as intermediates and transmit the power to the other two which are fastened to the shaft. When pawl *F* is engaged the whole case *J* is revolved and these gears are not turning, but are revolving with *J*. When arm *I* is engaged, and pawl *F* disengaged, the case *J* stands still and the gearing rotates. By this means I obtain the reversing movement which enables the dividing engine to give any kind of reverse movement needed.

When the dividing engine is ready to start, the operator throws the main switch *T*, which makes all electrical connections, including the direct current to run the electromagnets. Closing the switch *T* pulls up the rod *U*, allowing it to slip into the collar *X*, the thumb screw *Z* being released. The motor and the reversing parts are

now running but the engine is not. Wishing to start the engine, the operator raises the clutch arm *L*, at a certain stroke, forward or backward, allowing the trigger *M* to be engaged or cocked, the clutch being now in and the engine running. The thumb screw *Z* is now tightened, making the device ready for the automatic stopping. Having cut the required number of graduations on the scale, the counter or register, automatically makes electrical connection, exciting the electromagnet *R*, Fig. 3, thereby disengaging trigger *Q* and opening the main switch *T*. At the same time the clutch *O* is thrown out by the lever *L* and the entire apparatus is stopped. The opening of the clutch *O* stops the engine immediately while the motor may make a few revolutions, but all electrical connections are broken, and the knife *6* on the dividing head is left in a raised position. The writer intends, when time permits, to construct another automatic device to be run by compressed air, which will do away with many of the parts and eliminate the noisy hum of the motor.

The counter has an important and extremely necessary part to play. Every time a line is made the counter registers one, enabling the operator to know just how many lines have been made. The setting of the counter is done by subtracting the number of lines to be cut from the limit of the counter. The limit of the counter used is 10,000 so if it is desired to cut 360 lines the counter would be set at 9,640, and when zero comes in sight the machine stops automatically and the scale is cut.

The Brown and Sharpe Manufacturing Co. deserve great praise for their interest and their workmanship on the worm and gear of this machine. They stated in a letter to the department of physics that they could cut a gear that would be accurate to within five seconds of arc and it would appear from the calibration described below that, after proper lapping has been done, their statement will have been fulfilled.

In conclusion I wish to thank Professor Slate and the other members of the department of physics for their kind interest and valuable suggestions during the progress of the work.

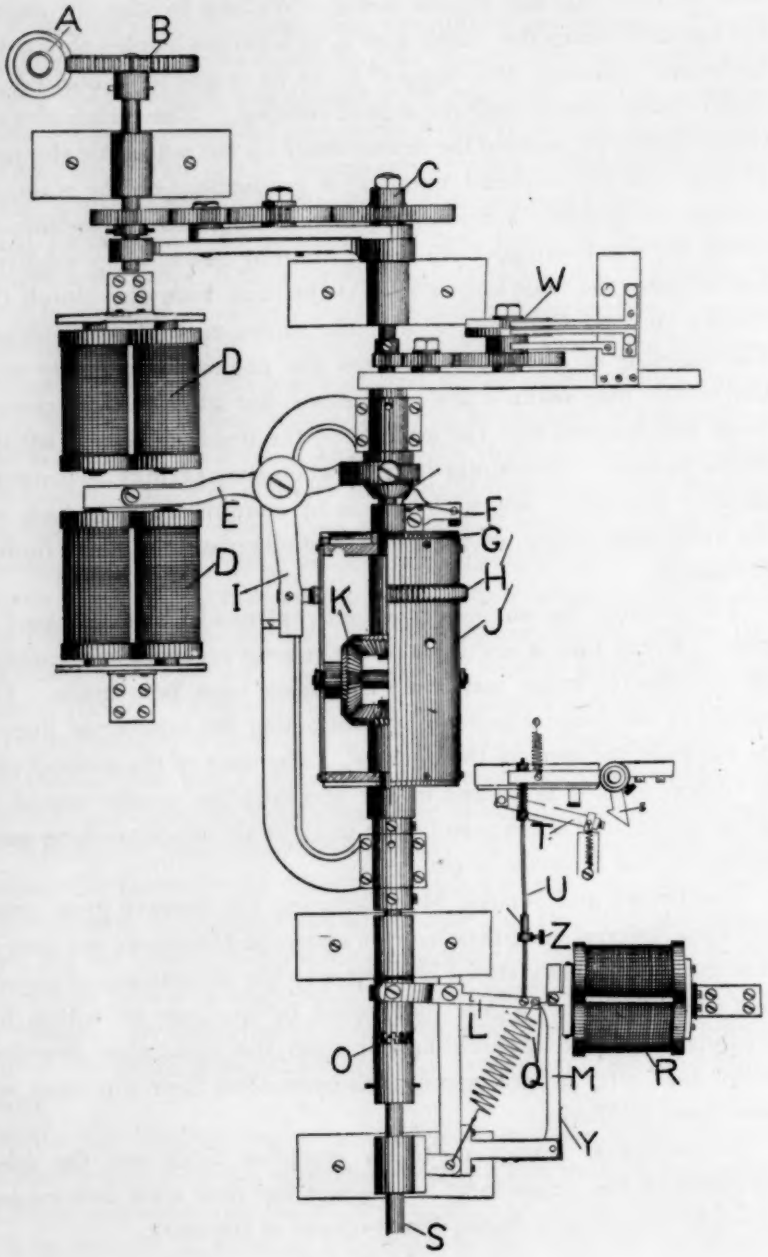

Fig. 3.

Calibration.

After the automatic dividing engine, described above, had been completed, and a few circles divided, it seemed desirable to calibrate the instrument, not merely to ascertain the errors of graduation but more especially as an aid in reducing these to a minimum by the further lapping of the gear wheel. The details of the calibration were carried out by Mr. T. A. Davidson, with the aid of Mr. Stamper and under the direction of the writer.

The method used was an optical one, a mirror being mounted on the axis of the main gear wheel in which the image of a fixed scale was observed through a fixed telescope. The scale was strongly illuminated, and placed about 20 meters from the dividing engine. The telescope system, placed close to the engine, consisted of an Edelmann telescope with an objective of 50 cm. focal length, the eye-piece of the telescope being replaced by a compound microscope. This arrangement gave clear definition and good magnification, enabling the scale to be read to 0.1 mm., and the aberration errors were negligible. The mirror was of speculum metal, finished by Brashear, and mounted in a wooden clamp which fitted into a brass collar attached to the shaft of the gear wheel. The mirror could thus be rotated around the shaft but would remain in the same position relative to the gear wheel during the taking of a reading. A small rod inserted horizontally in the clamp could be operated by means of a lever, provided with stops, thus enabling the observer to rotate the mirror back to the zero position without leaving his station at the telescope. The lever was arranged so as to move out of the way during the taking of a reading.

During the preliminary work several minor defects and peculiarities were noted and their disturbing effects in large part remedied. For example, the gear wheel was found to be very slightly eccentric. The introduction of a strip of platinum foil on one side between shaft and gear wheel caused a shifting of about one four-thousandth of an inch and almost completely remedied the defect. At first about 80 per cent. of the force moment necessary to start the gear wheel was supplied by an external weight system, the balance of the force moment being supplied by the worm. Consistent readings could not be obtained, owing to the unequal thick-

ness of the oil film on different parts of the gear and on the same part for succeeding revolutions. After a fresh application of oil successive readings might differ by as much as 15 seconds. Minute dust particles floating in the air and lodging on the gear or worm also caused variations of about the same magnitude. The suspended weight system was removed, allowing the worm to supply the entire force moment necessary to start the gear, and it was found that the force required was sufficient to reduce the film of oil between the bearing parts of the worm and gear to a uniform thickness as was evidenced by the consistent readings obtained. The oil used on the gear was "three in one," and, after the fresh application of oil, the gear was turned by the worm for several revolutions to secure as uniform a distribution of oil as possible. In actual work the engine with the circle which is being cut is protected by a glass covering case, thus reducing dangers from dust to a minimum. It was found moreover that the dust seemed to squeeze out from between the bearing surfaces with the oil, thus giving little trouble. Minute particles of lint floating in the air are more troublesome, since they neither crush or squeeze out with the oil. The tangential push exerted by the worm upon the gear in starting is about two pounds weight. Changes in temperature due to the presence of the operator and the small changes in temperature which occur from day to day produce only a negligible effect.

In the preparation of the calibration curve shown in Fig. 6 the initial readings were taken with two telescope systems, similar to the one described, placed 90° apart. First the reading of the scale was taken in one telescope, then the gear and mirror were rotated 45° and the reading taken in the second telescope. This was repeated several times around the circle, the average reading for each point being taken. It was by means of the eight points of the curve thus determined that the eccentric error of the gear was located and corrected. One telescope was now moved to a position 30° from the other telescope, which remained fixed throughout the entire calibration, and the two 15° points between each of the 45° points were located. The second telescope was again moved to a position 10° from the fixed telescope and the 5° points carefully located. The 1° points were then located using only one telescope.

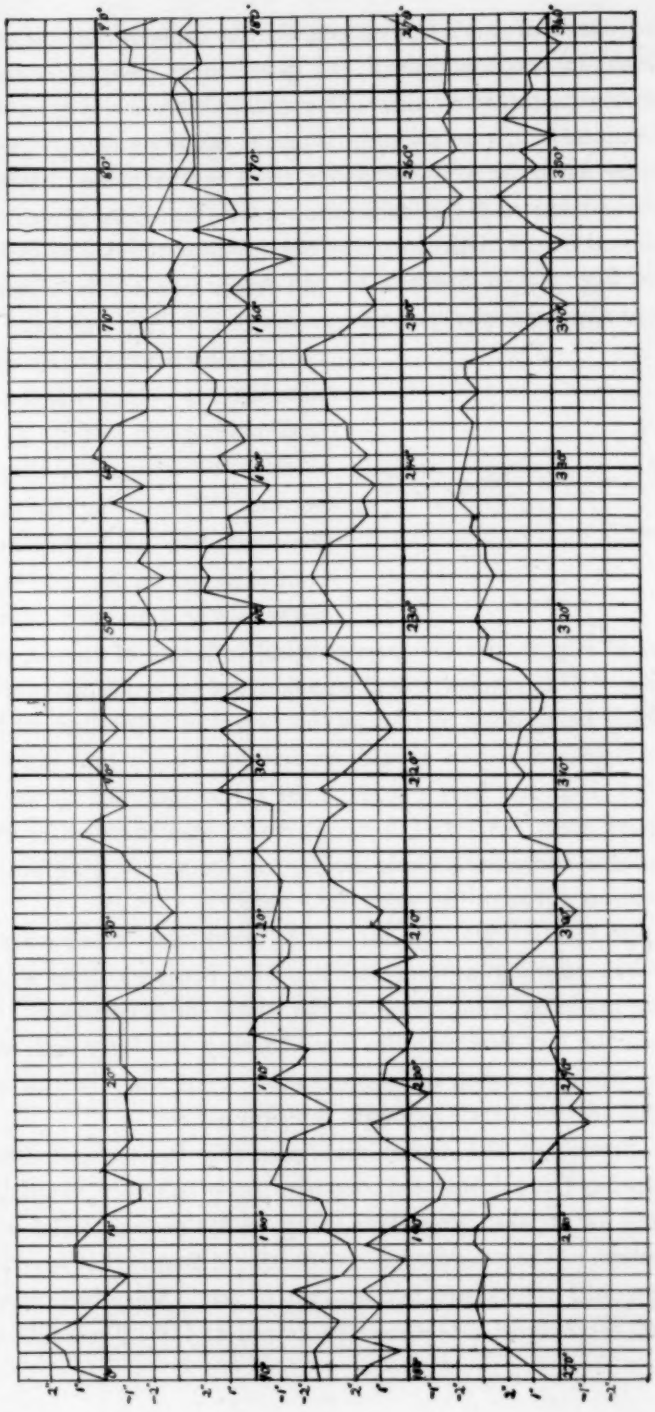

Fig. 4.

In the curve of Fig. 4, abscissas denote degrees corresponding to divisions on the top face of the gear wheel and the ordinates give errors in seconds of arc. The maximum error is seen to be about 8 seconds. In graduating a circle, fractions of a degree are obtained by means of a ratchet wheel. A ratchet wheel having $\frac{1}{6}°$ notches was used and the calibration curve found to agree, within observational errors, with the curve obtained for the degree divisions shown in Fig. 5. In addition to the errors due to the worm and gear there appeared the periodic errors due to the ratchet. The calibration curve for this particular ratchet wheel when in actual use is given in Fig. 5. The error is something less than one second. When using this ratchet the complete calibration curve would be given by adding the curve of Fig. 5 to each degree of the curve of Fig. 6, the two curves being reduced, of course, to the same scale. This ratchet wheel was first cut on a milling machine, the finishing being done by trial so that when in actual use with the worm and gear a degree would be divided closely into six equal parts. No circle has been cut since the errors detected by the calibration have been corrected, hence it is not known whether or not the calibration curve for a circle divided on the machine agrees with the calibration curve of the worm and gear.

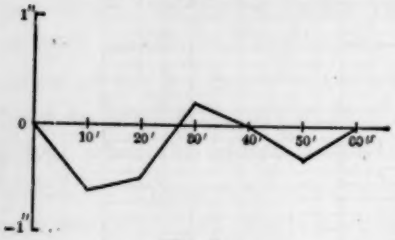

Fig. 5.

Readings for the $\frac{1}{6}°$ and for the 1° were also made when the machine was running automatically. The readings differ slightly from those made by hand, being on the whole more constant. This arises from the fact that with the hand turning, the force with which the wheel strikes the stop varies somewhat, while with the automatic turning the friction heads maintain uniform action.

When furnishing the worm and gear the Brown and Sharpe Manufacturing Co. advised the department of physics to continue the lapping for at least three days using an abrasive material which they supplied. They assured the department that if this were done the error would not exceed five seconds of arc. Very little lapping has as yet been done. It is now proposed to lay off a calibration

curve to proper scale on the face of the gear wheel, then during the process of lapping to increase the friction at the divisions denoted by the high places in the curve, the worm and gear being run by a motor. Arkansas stone dust will be used as abrasive material for this final lapping. It is hoped that by this systematic lapping the error may be reduced to at least one half of its present value.

UNIVERSITY OF CALIFORNIA,
DEPARTMENT OF PHYSICS,
July 10, 1909.

COEFFICIENT OF EXPANSION OF NICKEL NEAR ITS CRITICAL TEMPERATURE.

BY WALTER F. COLBY.

THE coefficient of expansion of nickel at ordinary temperatures was investigated by Fizeau in 1869. He used an interference method in which the expansion of the object was measured by the movement of a set of interference fringes. His method [1] of determining this displacement made possible the measurement of an expansion in the object under examination, of .02 wave-length of the light used. The delicacy of measurement was such that the coefficient of expansion of objects of but 1 cm. length could be determined with a high degree of accuracy. The improvements which have been made upon the method of Fizeau, notably by Benoit,[2] Abbe[3] and Pulfrich,[4] have been largely in the direction of increasing the ease and accuracy with which the displacement of the interference fringes can be observed and measured. In the Pulfrich interferometer, the instrument used in this investigation, we have undoubtedly the highest type of apparatus used for this purpose. In certain other methods which have been employed it has been necessary to use specimens 50 cm. long to reduce the percentage of error in measuring changes of length due to expansion. This greatly increases the difficulty in establishing and maintaining a uniform temperature, and in consequence only values of the mean coefficient over long ranges of temperature have been possible. In the present study it was desired so to refine the temperature measurements that ranges of five degrees might be used through a special region, *i. e.*, that of the critical temperature. The Pulfrich interferometer is extremely well adapted to this, allowing, as it does, high accuracy of measurements with small specimens.

[1] Ann. d. Chemie de Phys., 2, p. 143, 1864; 8, p. 335, 1866.

[2] Trav. et Mem. du Bureau Int. Poids et Mes., I., 1181; VI., 1888.

[3] Wied. Ann., 38, p. 453, 1889.

[4] Zeitschr. für Instr., 1893, pp. 365, 401, 435.

Le Chatelier in 1888 published values of this coefficient for high temperatures, but not until recently were any precise measurements made in the critical region.

In 1901, Holborn and Day[1] studied the expansion of metal rods, 50 cm. long in an electrically heated porcelain tube. Readings were taken on scratches near the ends of the rods and the temperatures measured by means of a thermal couple placed at the middle. The results below 300° were expressed as a quadratic function of the temperature. Above 300° this function no longer held, the linear term becoming smaller and the quadratic larger. The temperature throughout the bar was far from uniform, and the method therefore could throw no light on the nature of the change at 300°.

Harrison[2] in 1904 made a similar investigation, using a nickel wire 60 cm. long, kept under tension by an adjustable spring. Lengths were measured by telescopes 10 cm. apart at the mid portion of the wire. He found an anomalous expansion at 370°, the critical temperature of his specimen. Between this temperature and 380° the wire experienced an elongation of about .05 per cent., whereas in the preceding ten degrees the elongation had been only .002 per cent. Above 380° the rate became .0019 per cent. per 10°. The discrepancy between these results and those of Holborn and Day may be explained by assuming that the elongation of the wire, due to the decrease of the elastic constant with rising temperature[3] increased the absolute value of the coefficient. Temperatures were in this instance measured by the resistance of 20 cm. of the nickel wire itself, the calibration of which is not described in the article. The temperature recorded was therefore the mean throughout this length. The wire was placed centrally in a groove cut in a mahogany board and covered with a strip of wood with mica windows. Losses by unequal radiation and conduction through the leads were evidently considered too great for uniformity of temperature as results were computed only for fifty degree ranges.

Randall[4] in a recent paper has described his work in this field. He worked with a solid nickel cylinder 1 cm. long and 2 cm. in

[1] Ann. d. Phys., 4, 104.
[2] Phil. Mag., June, 1904.
[3] Pogg. Ann., 145, p. 147, 1872.
[4] PHYS. REV., February, 1905.

diameter, employing an interference method and using the Pulfrich interferometer to measure the displacement of the fringe system. Temperature measurements were made with mercury thermometers, and although uniformity of temperature seemed certain, stem corrections may easily have introduced errors of such magnitude that measurement of temperature differences for intervals of less than twenty degrees became doubtful. With small ranges a slight constant error in each of the two temperatures, whose difference constituted the temperature interval, would not have materially altered the results. These stem corrections however were dependent on the temperature gradient of the oven packing, which in turn depended on the thermal history both of the oven and the room. Thus no error could be considered constant. Even these small ranges of twenty degrees may mask an anomaly. This specimen lost its magnetism at about 310°. The results showed no such anomaly at the critical point as those of Harrison. The coefficient increased steadily till about 275° and from there to 400° remained almost constant.

The present work grew out of this disagreement and takes as its problem the further refinement of temperature measurements and the investigation of other specimens of nickel. Three specimens have been used, which for convenience will be designated by the letters A, B and C. The work was begun in 1907 and preliminary tests made with specimen A. These were repeated in 1908 with slight modifications, and the same tests applied to B and C.

MAGNETIC MEASUREMENTS.

The first part of the problem consisted in finding definitely the temperature region in which magnetizability disappeared for the different specimens. A and B, being annular in shape, were wound ringwise with a primary and secondary of copper wire insulated with asbestos paste. A thermal junction of iron constantan encircled the nickel in direct contact with it, and was firmly fixed by the insulation. The whole was placed in an electric oven having an inner chamber of porcelain surrounded by 10 cm. of mineral wool. A current of one ampere was passed through the primary and the effect of its reversal noted by a ballistic galvanometer in

series with the secondary. Temperatures were measured by means of a Siemens and Halske potentiometer after the design of Lindeck and Rothe.[1] The preliminary tests were made first with temperature steadily rising to points somewhat above critical temperature and then steadily falling to room temperature, to ascertain the type of the curve. This excluded possibilities of overlooking an abrupt anomaly which might easily fall between two stationary temperatures. It gave, of course, no truly corresponding values of temperature and deflection, and, plotting these quantities as coördinates, the resulting curves for heating and cooling naturally included a considerable area, since the change of temperature of the interior of the nickel lagged behind that of the thermal junction. In the final tests each temperature was maintained from twenty to thirty minutes, allowing, it was thought, ample time for such thermal equilibrium as this test demanded. If the change of temperature was not great, the galvanometer deflection gradually increased during the first five minutes of the new temperature but was afterwards constant. Even in the steep portions of the curve the deflections gave no evidence of an unstable state. Although the included area was here greatly reduced, it did not disappear, showing a slight temperature hysteresis.

Fig. 3 (p. 518) shows the results obtained with specimen A. The loss of magnetic properties occurred here in the region between 370° and 380° and at temperatures just below 370° a decided rise in permeability was found both on heating and cooling. No such maximum occurred in the curve for specimen B (Fig. 4) although the method and strength of field were the same. Here the phenomenon took place at a very much lower temperature, between 280° and 310°, showing a marked difference in purity or in structure of the nickel. Specimen C was a cylinder 8 mm. in length and 2 cm. in diameter. The ballistic method was again used but the cylinder was placed inside a glass tube on which a primary and secondary were wound for a distance of about 4 cm. The sensitiveness was so much reduced that it was necessary to use a current of six amperes to obtain reliable results. Except in magnitude, the curve (Fig. 5) did not differ from that of specimen B, the region centering about 312°.

[1] Zeitschr. für Instr., 20, p. 285, 1900.

OPTICAL SYSTEM.

Since the method used in this investigation for measuring the changes in length caused by expansion, has been fully described,[1] it will be necessary only to outline it briefly and to denote adaptations to this problem. It consists fundamentally in the production of interference fringes by two plane reflecting surfaces, opposite and slightly inclined to one another, whose distance apart changes with the length of the specimen. The bands are viewed and their displacement measured by means of a Pulfrich interferometer (Fig. 1). Light from the source of illumination is focused on a totally

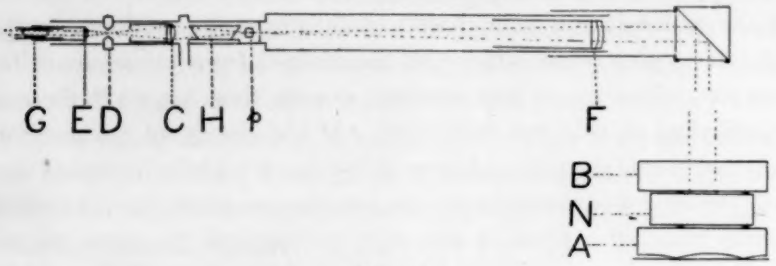

Fig. 1.

reflecting prism p, placed at the focus of the objective F. Approximately parallel rays emerge from the objective and are reflected downwards by another totally reflecting prism at the end of the interferometer tube. These rays are reflected from the optical surfaces, reënter the objective and after passing the free half of the telescope at prism p, and a second lens C, are brought to a focus at an adjustable horizontal slit D, immediately in front of two vertical cross hairs. Adjustment of lenses C and E brings the cross hairs and the images of the fringes in sharp outline. These are viewed through the direct vision spectroscope G and the horizontal images of the slit thus appear in the spectral colors. The images of the interference bands are visible in each of the slit images and can be made vertical by rotating the Dove's prism H. A micrometer attachment makes it possible to move the cross hairs parallel to themselves and thus to measure the distance of any interference band from a fiducial mark in the field.

[1] Pulfrich, Zeitschr. für Instr., 1893, pp. 365, 401, 435. Randall, PHYS. REV., February, 1905.

Specimen A was in the form of a ring 8.2 mm. long, 5 cm. internal diameter and 4 cm. external diameter. Specimen B, also a ring, was 2.3 cm. long, 2 cm. internal diameter and 3 cm. external diameter. Both ends of these rings had been ground away so as to form three equidistant feet. The optical system for these tests was formed by placing the nickel ring *N* on a quartz bed plate *A*, with upper surface plane polished and lower surface ground that it might give no disturbing reflections. The ring was surmounted by a similar plate *B*, both sides of which were plane polished. On the lower side was etched a small circle which was used as a point of reference in the measurements. To avoid reflections from the upper surface this cover plate was ground slightly wedge-shaped. For the preliminary tests this lower surface of the upper plate and the upper surface of the lower plate were used as reflecting surfaces, but their distance was so great that the clearness of the bands was not sufficient for the best results. For the final tests, accordingly, this air layer was reduced to a thickness of approximately 1 mm. by placing a fused quartz cylinder, with upper surface plane polished and lower surface ground so as to form three feet, on the bed plate *A* (Fig. 1) inside the nickel ring *N*. The coefficient of expansion of the quartz is so small in comparison with that of the nickel that when added to it it does not affect the first two significant figures. Any error in the value of the quartz coefficient or in the length of the quartz specimen would therefore appear outside the limits of error of the nickel. The increased distinctness of the bands doubtless more than compensated for the error introduced by this new material. Specimen *C*, being a circular cylinder, 1 cm. long and 2 cm. in diameter, was ground similarly to the quartz cylinder just described and placed inside a fused quartz ring. Since the surface of the nickel did not preserve its polish at high temperatures, it was surmounted by a thin fused quartz disk. This arrangement left an air layer of 0.2 mm. between the bottom of the cover plate and the upper surface of the quartz disk, producing a very satisfactory fringe system.

Illumination.

Illumination was produced by an Arons mercury lamp. The light was very brilliant and steady, and for the thin air layers used

in these tests, the green ($\lambda = 546\ \mu\mu$) and two yellow bands ($\lambda_1 = 578.8\ \mu\mu$, $\lambda_2 = 576.8\ \mu\mu$) were sharply defined. These two yellow lines of the spectrum were not competely separated by the direct vision spectroscope of the interferometer but overlapped for a considerable part of their width. Consequently the dark interference bands which crossed them transversely were at times so completely superposed that settings were made on their common dark portion and the mean wave-length used in computations. Later in the same series the relative shift of these dark bands made it necessary to use the "upper yellow" alone.

THE OVEN.

The oven (Fig. 2) consisted of a vertical cylindrical iron frame formed by two rings 15 cm. in diameter connected by rods 35 cm. long. This, being well insulated with asbestos, was wound lengthwise with german silver wire R and surrounded by packing 8 cm. thick of alternate layers of asbestos and infusorial earth. This shell rested on a thick pad of asbestos through the center of which rose two porcelain rods, supports for the optical system. The top consisted likewise of an asbestos pad resting on a porcelain lid. An asbestos chimney A, fitted transversely with four squares of plate glass, penetrated the cover. All joints were closely packed with infusorial earth. The whole rested on a platform supported from the asphalt floor by steel rods clamped to the brick pier. The porcelain rods P, entering from below, supported a cylindrical brass chamber C, coated with asbestos and fitted at the top with a glass window. A brass disk D, resting on three leveling screws in the bottom, formed a base for the optical system. Two platinum thermometers T were firmly attached to the porcelain rods. The bulb of one was introduced into the inner chamber and the other placed in the air chamber outside in the same horizontal plane as the optical system. Since the heating coil was suspended in the outer chamber and free to air currents, it seemed evident that the temperature of that chamber would be almost immediately affected by any adjustment of the heating current, whereas the inner chamber because of its thermal capacity and asbestos coating would lag behind those changes and tend to remain constant, especially if the fluctuations

in the temperature of the surrounding air were somewhat rapid. The winding of the heating coil was such that it produced very slight effect on the magnetic field at the center of the oven. A

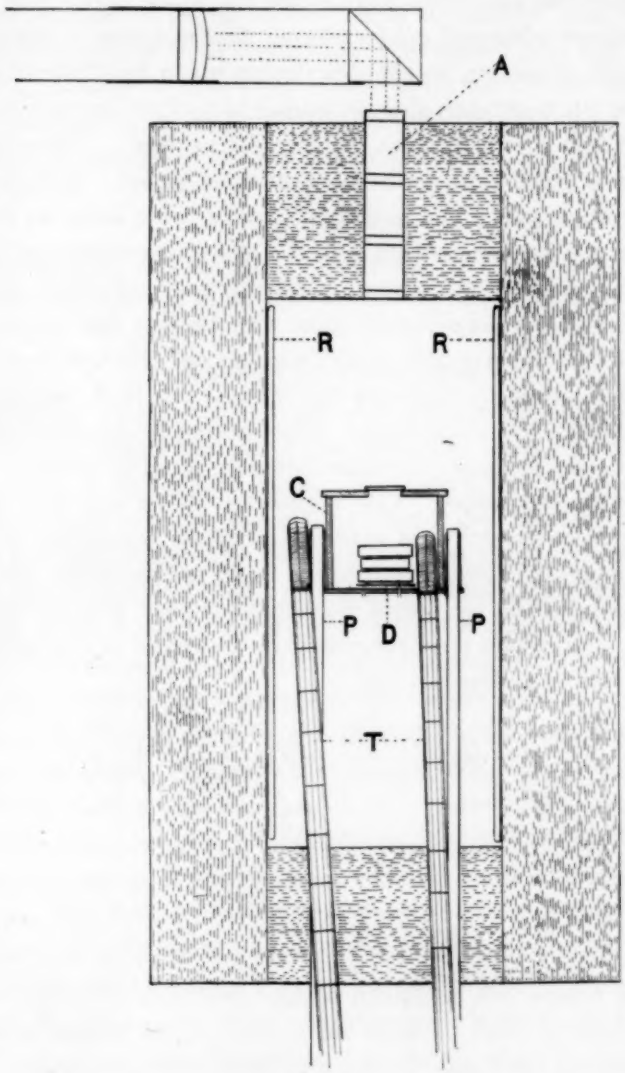

Fig. 2.

part of the heating current, however, was passed through a coil wound about the outside of the oven and so adjusted that no meas-

urable magnetic effect could be detected in the vicinity of the specimen.

THERMOMETERS.

The two thermometers were made by winding on mica vanes, fine platinum wires and gold soldering the terminals to heavy platinum leads, according to the description given by Callendar.[1] To eliminate the resistance of these leads a loop of similar wire identical in length was mounted close and parallel to them. The whole was fitted in a glass tube with the bulb end sealed. Circular mica disks through which the four leads passed were fitted at frequent intervals in the stem both to hold the leads in position and prevent air currents. The resistances of the thermometers were measured by means of a Carey-Foster slide wire bridge, the thermometer being used as an extension of the wire on one side and a resistance box and the dummy leads on the other. The lead resistance was thus automatically eliminated. The box and bridge wire were calibrated to six decimal places by comparison with standard resistances in the laboratory. One millimeter of the wire had a resistance of .000718 ohm and readings could be estimated to tenths of millimeters. The thermometers were calibrated by measuring their resistances in ice, steam, naphthaline vapor and sulphur vapor baths. The results were expressed by means of the parabolic formula given by Callendar, viz.,

$$t = 100\frac{R_t - R_0}{R_{100} - R_0} + d\left(\frac{t}{100} - 1\right)\frac{t}{100}.$$

R_0	for thermometer		I., 39.59842 ohms.
d	"	"	I., 1.554
R	"	"	II., 40.82634
d	"	"	II., 1.568

These values give a change of approximately one ohm for each ten degrees or .007° for each millimeter on the bridge wire. The galvanometer used was of such sensibility that the current passing through the bridg could be made small enough to eliminate heating effect in the thermometer. To guard against thermal effects

[1] Phil. Mag., 47, 191.

the wire and contact key of the bridge were of manganin, as were all resistance coils so that the entire circuit, with the exception of the platinum thermometers, was composed of manganin and copper. The junctions of the platinum leads with the copper leads connecting the thermometer with the bridge, were placed near one another to insure, if possible, the same temperature for all the junctions. These measures seem to have been sufficiently effectual, since no disturbing irregularities were experienced during the progress of the work.

Spherometer.

A spherometer was used to measure the length of the rings and cylinders. It was made by the Geneva Society and read directly to .001 mm.

Method of Procedure.

To produce satisfactory fringes the lower surface of the cover plate and the upper surface of the bed plate must be inclined to one another at the proper angle. This angle was found by trial. The nickel rings were so adjusted by careful grindings of their feet, that, when placed between the cover and bed plates, fringes of the desired width were obtained. A fringe width of approximately one hundred scale divisions, as measured by the micrometer adjustment at the eye piece of the interferometer, was found to give most satisfactory results. It was feared there might be some irregularities due to air films or particles of dust between the points of contact of plates and rings. After the optical system had once been heated to 500° the band width was practically constant and without tilt, and on examination it even required some pressure of the fingers to separate the parts; moreover, while the application of pressure to the cover plate before heating produced a noticeable movement of the fringes, after being heated to 500°, a weight of 100 to 200 gms. on the cover plate produced no measurable effect. The oven was therefore heated to 500° before beginning each series, that this apparently more permanent condition might be attained.

The optical arrangements being thus in order, the oven was raised to the desired temperature by frequent adjustment of the heating current. To accomplish this the bridge was connected with the thermometer in the outer chamber and set at the desired reading,

the galvanometer being kept at the zero point by manipulation of a variable resistance in the heating circuit. For the first reading this was continued from three to five hours, for the later readings from two to three hours. Maximum variation in the outer chamber was .04°, in the inner chamber about .01°. The temperature of the inner chamber was recorded both before and after and sometimes in the midst of the reading taken on the fringe system with the interferometer. The temperature of the outer chamber was then changed and the number of bands passing the reference circle noted. Readings were taken on the green and yellow bands and Abbe's[1] computation used as a check on the number of bands counted during the shift. If δ_2 be the distance from the zero point to the nearest band in fractions of a band width at the higher temperature, δ_1 a similar quantity at the lower temperature and M the whole number of bands passed, then the apparent shift $t_1 = M + \delta_2 - \delta_1$.

At each interferometer reading a barometer reading was also taken and Pulfrich's[2] correction applied for change of wave-length in the air layer due to change in density. This correction is

$$K = d(t_2 - t_1)\frac{b_1}{760}\frac{1}{1 + at_1}\frac{1}{1 + at_2}\left[\frac{2(N-1)a}{\lambda}\right]$$

$$- d(b_2 - b_1)\frac{1}{1 + at_2}\left[2\frac{N-1}{\lambda}\frac{1}{760}\right].$$

Where d is the thickness of air layer, t_2 the higher temperature, t_1 the lower temperature, b_2 and b_1 the corresponding barometric readings, a the coefficient of expansion of air and n the index of refraction of air under standard conditions. K is here expressed in terms of band widths. The first term, a correction for the increased temperature, is always positive. The second, a correction for change in barometric pressure, is negative when $(b_2 - b_1)$ is positive, that is, when the greater pressure occurs at the higher temperature. If the apparent shift t_1 be taken as positive for increasing and negative for decreasing thickness of air film, the absolute value of true shift $f = f_1 + k$. The change of length is $f \cdot \lambda/2$.

[1] Wied. Ann., 38, 1889, p. 473.

[2] Zeitschr. für Instr., p. 437, 1893.

Degree of Accuracy.

The formula expressing the value of the coefficient of expansion is:

$$\alpha = \frac{f\frac{\lambda}{2}}{L(t_2 - t_1)} + \frac{l\alpha'}{L}.$$

Where l and α' denote respectively the length and coefficient of expansion of the fused quartz cylinder or ring and L the length of the nickel specimen. The value of α' was taken from recent, unpublished work of Randall's in which he expresses the true coefficient by the parabolic formula:

$$\alpha \cdot 10^8 = 41.94 + .156\theta - .000225\theta^2,$$

giving an almost constant value through this region of 68×10^{-8}.

The value of f, the number of displaced fringes, is dependent on two measurements each of which can be determined within a probable error of .01 band, giving a probable error for f of $\pm .015$. The temperature interval $(t_2 - t_1)$ is likewise dependent on two measurements. The sensitiveness of the bridge made readings of the platinum thermometers definite to half millimeters on the bridge wire or .0035°. Variations in these readings, however, might be due to two causes, actual variation in the inner chamber and irregularities of the bridge. Two or three readings were taken for each determination of the band position, these determinations occupying approximately fifteen minutes. These temperature readings were usually very much in accord, and in fully seven eighths of the observations did not vary more than .01°. In a few cases, irregularities in the heating current which could not be properly compensated during the band determination, caused fluctuations in the inner chamber as great as .07°. For the greatest of these variations, the temperature was maintained an hour longer and the reading repeated. The probable error for the majority of the temperature readings was computed from the sets of temperature readings taken during a determination of the band position and found to be $\pm .0075°$, giving for $(t_2 - t_1)$ a probable error of $\pm .010°$. The length of the nickel L may be determined within a mean error of $\pm .001$ mm.

For specimen A the shift for a change of temperature of ten degrees was about five bands. The error in α due to f for this interval amounts to 4.9×10^{-8}; due to error in L, $.2 \times 10^{-8}$; due to error in $(t_2 - t_1)$, 1.6×10^{-8}; giving a probable error in α due to the three quantities of $\pm 10.2 \times 10^{-8}$. Similarly for specimen B. Its length was 23.01 mm. and the shift for ten degrees, 14 bands. The error in α for 10° intervals was $\pm 2.4 \times 10^{-8}$, for 5° intervals $\pm 4.8 \times 10^{-8}$. Specimen C was 7.88 mm. long and gave for 10° a shift of 5 bands. 10° intervals, accordingly, gave results within a probable error of $\pm 5.45 \times 10^{-8}$ and 5° intervals $\pm 10.9 \times 10^{-8}$.

In series II. of specimen A, two successive values of α lie considerably outside this probable error. It was not possible to trace the cause of this but since the first is too high and the second too low, it

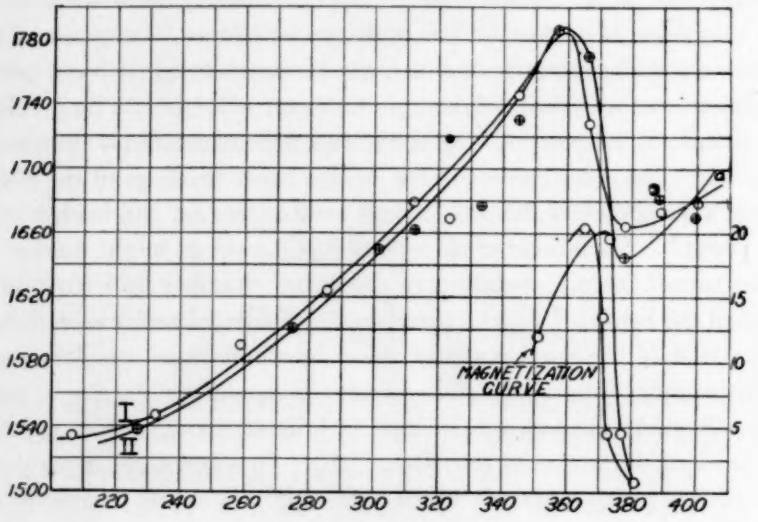

Fig. 3. Specimen A.

does not seem unreasonable that a mistake was made in reading the mid temperature on which they both depended. It was possible to pass a consistent curve through the majority of the values of α. In fact only six of the results were distant from these curves by an amount exceeding their respective mean errors.

The results for the three specimens are shown in Figures 3, 4, and 5. During the first series, with specimen C, corrosion of

the bridge wire so reduced the sensitiveness of the temperature measurements that all results for less than 20-degree intervals were discarded. A thorough cleaning of the bridge restored accuracy for series II. As had been found in the preliminary tests, series II. could not be combined with series I., the value of the coefficient being dependent on the thermal history of the specimen. The values of the coefficient have been plotted as ordinates, with mean temperatures as abscissas, and the resulting curves show a striking similarity for the three specimens.

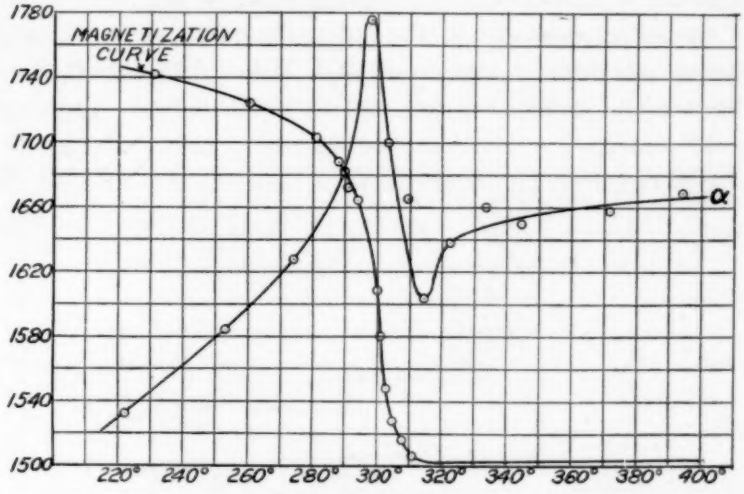

Fig. 4. Specimen B.

Specimen A is electrolytically prepared, and although a quantitative analysis has not yet been secured, it may be presumed to be unusually free from impurities. A qualitative test shows only a trace of cobalt. Its critical point lies 60° higher than the others and coincides very closely with the anomaly in expansion. This coincidence is equally good for the other two specimens, although the anomaly itself varies in magnitude. Specimen B was cut from a rolled nickel rod obtained from the Westphalian Nickel Works, and judging from its color on oxidation, contains far more iron than A and doubtless other impurities. Specimen C is the one used by Randall and was prepared by Zeiss of Jena. Its color on oxidation is similar to that of B, but the anomaly is far less marked.

For the sake of comparison with Randall's curve, computations of α were made for 20-degree intervals and the resulting curve plotted. With one or two exceptions, the values did not vary from his outside the limits of error.

No results have been given from the preliminary work with specimen A in 1907, but at least a brief mention of them should be made. The oven and optical system in this series differed in no way from those of 1908, but instead of the platinum thermometers, two groups of seven copper advance thermal junctions were used. One group was placed at equal intervals about the nickel in the inner chamber and the other similarly in the outer chamber. A Wolff potentiometer was used to measure their E.M.F. Although their sensitiveness and quick response was very satisfactory, the copper

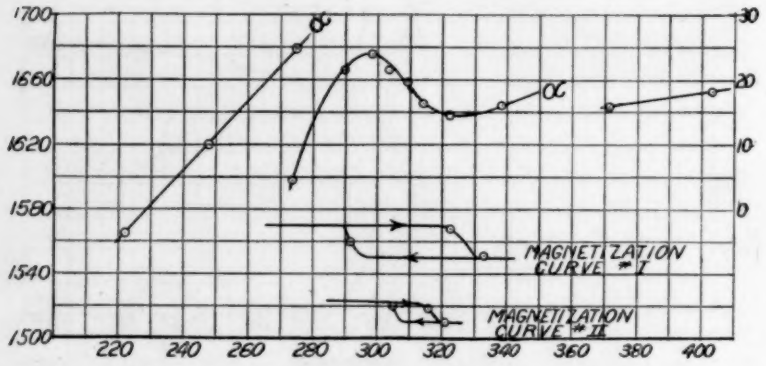

Fig. 5. Specimen C.

oxidized so readily at the high temperature and they soon became so fragile, that it was impossible to work with them. The observations in this work were unfortunately always discontinued at the close of each day and the isolated groups of about five readings, although consistent with each other, could never be satisfactorily combined with those of the following day. As mentioned above, this was due to the well-known change in the value of the coefficient of expansion of metals at a given temperature after the metal has been heated. The type of the curves which the readings suggested, however, agreed with that found in the later work, showing a decrease in a special region and an increase on either side.

In conclusion the results may be summarized as follows:

1. The electrolytically prepared specimen shows a high value of permeability just below its critical temperature. This phenomenon is absent in the other specimens and is possibly due to the greater purity or crystalline structure of specimen A.

2. For the first sample, the critical temperature is in the neighborhood of 370° and, as in the case of iron, is lowered by impurities.

3. The absolute value of the expansion coefficient is in part dependent on the history of the specimen.

4. Through a continuous heating the relative values show an increase at the beginning of the region followed by a decrease.

5. Before and after the critical regions, the coefficient increases at a regular rate.

The writer wishes to express his gratitude to Professor Randall both for his aid in the final determinations and his invaluable suggestions throughout the work.

NOTE ON THE RELATION BETWEEN THE TEMPERATURE AND THE RESISTANCE OF NICKEL.

BY C. F. MARVIN.

THE splendid work of Callendar confirmed and extended by many others has placed in the hands of physicists that admirable and indispensable tool, the platinum resistance thermometer.

All this work demonstrates that the relation between the temperature and the resistance of platinum wires can be represented over a very wide range of temperature by a parabolic curve, such as given by an equation of this form:

$$R = R_0 + \frac{R_{100} - R_0}{100}\left\{T - \delta\left[\left(\frac{T}{100}\right)^2 - \left(\frac{T}{100}\right)\right]\right\} \qquad (1)$$

or in simpler form:

$$R = R_0 + aT - bT^2. \qquad (2)$$

This equation is due to Callendar who has pointed out that the constant δ depends only on the quality, or purity, of the particular sample of platinum employed. R_0 and R_{100} are the resistances of the thermometer coil at 0° and 100° C., respectively.

Probably no other metal can compete with platinum for use at high temperatures, but it is believed the striking advantages in nickel wire for the construction of resistance thermometers over a considerable range of moderate temperatures is not generally recognized.

Nickel exhibits an inversion point between 350° and 400° C., and sufficient data to determine its suitability for resistance thermometers at very low temperatures are not at present available. Its greater resistance, greater change of resistance with temperature, and its small cost as compared with platinum, all render nickel better than platinum for thermometric purposes over a considerable range of temperatures. While it may possibly be difficult to

procure nickel wires of a uniformly high purity, yet the maximum purity seems unessential since what passes as commercially pure nickel seems to possess the advantages now in mind. Callendar has already shown that the temperature resistance curve of platinum is a parabola. At least three points must be located to define the parabolic curve.

The nickel resistance curve seems to be very accurately represented by a logarithmic curve of this form:

$$\text{Log } R = a + mT. \qquad (3)$$

Table of Observed and Calculated Resistances of Nickel-Resistance Thermometers.

A				B				C			
Tem. ° C.	Resistance.		Dif. Ob. − Cal. ‰.	Tem. ° C.	Resistance.		Dif. Ob. − Cal. ‰.	Tem. ° C.	Resistance.		Dif. Ob. − Cal. ‰.
	Obsd.	Calc.			Obsd.	Calc.			Obsd.	Calc.	
−25	11.030	11.036	−.05	−27.7	70.72	70.79	−.10				
−20	11.250	11.254	−.04	−27.6	70.74	70.82	−.11	0[1]	8.42	9.10	− 7.5
−15	11.475	11.477	−.02	−24.6	71.64	71.71	−.10	100	12.66	12.73	− 0.5
−10	11.700	11.703	−.02	−23.6	72.34	72.02	+.45	200	17.97	17.80	+ 0.9
− 5	11.935	11.935	±.00	−23.6	71.92	72.02	−.14	300	24.95	24.90	+ 0.2
0	12.173	12.173	±.00	−18.4	73.57	73.60	−.04	325	27.06	27.08	− 0.1
+ 5	12.420	12.413	+.06	−12.9	75.39	75.32	+.09	350	29.33	29.45	− 0.4
10	12.660	12.659	+.01	− 7.04	77.29	77.20	+.12	375	31.98	32.02	− 0.1
15	12.920	12.908	+.10	− 5.95	77.65	77.55	+.13	400[1]	33.67	34.84	− 3.5
20	13.173	13.163	+.08	+ 8.4	82.42	82.36	+.06	425[1]	34.70	37.87	− 8.4
25	13.435	13.423	+.09	8.8	82.54	82.50	+.05	450[1]	35.63	41.19	−15.6
30	13.700	13.689	+.08	9.0	82.61	82.57	+.05				
35	13.965	13.959	+.04	9.2	82.70	82.64	+.07				
40	14.240	14.235	+.04	11.38	83.44	83.40	+.05				
45	14.520	14.516	+.03	23.76	87.70	87.84	−.16				
50	14.800	14.802	−.01	24.05	87.82	87.95	−.15				
55	15.080	15.093	−.09								
60	15.385	15.393	−.05								
65	15.690	15.697	−.05								
70	16.000	16.007	−.04								
75	16.320	16.323	−.02								

[1] Not included in computation of equation.

A = Thermometer made by Leeds & Northrup for Weather Bureau for the measurement of solar radiation:

$$\text{Equation: Log } R = 1.08539 + .001699t. \qquad (4)$$

B = Data supplied by Leeds & Northrup.

$$\text{Equation: Log } R = 1.90045 + .001818t. \qquad (5)$$

C = Data supplied by Bureau of Standards on a single specimen of wire regarded as impure:

$$\text{Equation: Log } R = 0.96145 + .00145t. \qquad (6)$$

Only two points are required to locate such a curve. The coefficient m depends upon the quality, that is, the purity, and possibly some other of the physical properties and conditions of the metal.

The data at present available to the writer in support of the logarithmic curve is conceded to be too scanty and inadequate to demonstrate anything like a general law, but the conformity is sufficient for a great many purposes, and is shown in the following table:

In the two thermometers from Leeds & Northrup the conformity to the logarithmic equation is really very close, although no great range of temperature is embraced. The residuals are of about the same order of magnitude as the probable accuracy of the resistance measurements, viz: one tenth of one per cent.

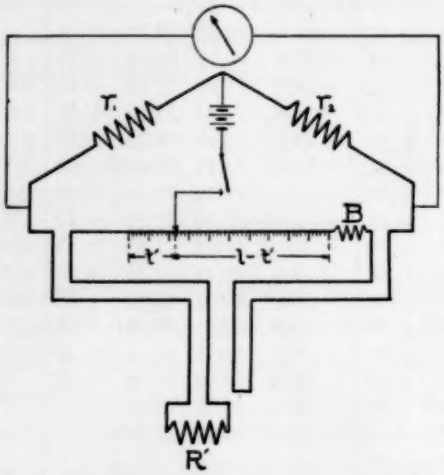

Fig. 1. Theoretical diagram of Wheatstone's bridge.

The data from the Bureau of Standards are not so well fitted by a logarithmic curve. The point at zero degrees, especially, is discordant, but from 100° to 375° the conformity is much closer.

Admitting that the nickel wire temperature resistance curve is approximately logarithmic, it remains to point out that resistance readings of a nickel thermometer on the usual form of slide-wire bridge, or equivalent, having a scale of equal parts, may also be made to give gas scale temperatures with a very considerable accuracy.

The two diagrams, Figs. 1 and 2, show two forms of bridge connections commonly employed in this kind of work. We consider only in each case a scale of equal parts. Any scale of unequal parts is an undesirable, if not an impracticable or impossible, thing.

The relation between resistance and scale reading in the Fig. 1 arrangement is strictly linear, and therefore the scale readings show temperatures on the gas scale only when the resistance of the ther-

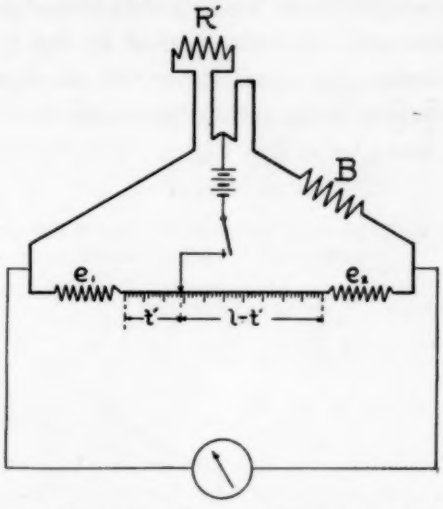

Fig. 2. Theoretical diagram of Wheatstone's bridge.

mometer varies according to a strictly linear law. This arrangement is used extensively with the platinum thermometer, and the scale readings are the so-called platinum temperatures.

In the arrangement of Fig. 2 the relation between the scale readings t' and the resistance R' is given by the equation:

$$R' = B\frac{e + t'}{e + l - t'} \quad \text{when} \quad e_1 = e_2. \tag{7}$$

The curve represented by this equation between R' and t' is concave upward as is also the logarithmic curve representing nickel resistance, viz:

$$\text{Log } R = a + mt. \tag{3}$$

I now wish to show that a section of the $R't'$ curve, representing a temperature range of say 50° to 100° will conform with extreme

closeness to the logarithmic curve over the same range; that is, the t' scale of the bridge is then accurately the gas temperature scale.

Suppose, for example, we want the extreme range of the bridge scale to embrace 100 degrees of temperature, say from t_1 to t_2. Now, the $R't'$ curve can be made to intersect the Rt logarithmic curve in two points determined by the two constants, B and e (l = the resistance of the whole bridge wire, is determined by the range of temperature embraced, viz: 100 degrees in this case). The two curves will conform most closely over the whole range when the points of intersection lie at certain particular points between the two extremes t_1 and t_2 as at PQ, Fig. 3.

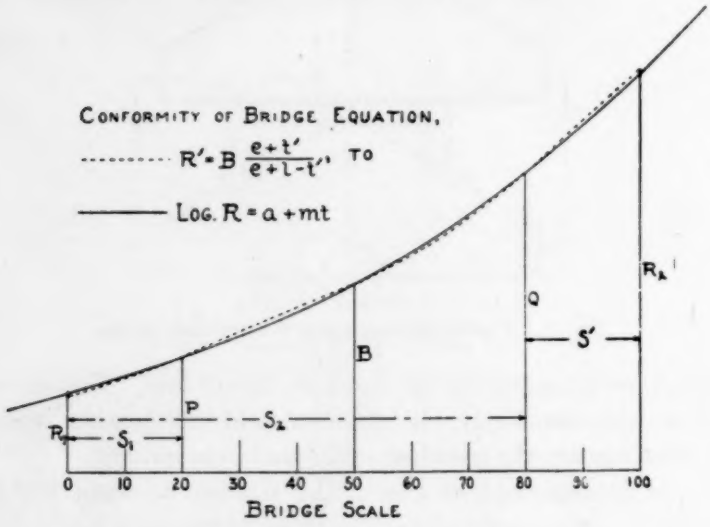

Fig. 3.

It is quite sufficient to select the two points, PQ, arbitrarily for example, at say $\frac{1}{4}l$, and $\frac{3}{4}l$. We can even pass the $R't'$ curve through the points t_1 and t_2, or through t_1 and the middle point m, or through m and t_2. The deviation of the curves one from the other is smaller, as a rule, than the ordinary errors of observation, except in work of the highest precision. The general equations for computing the values of B and e giving two intersections intermediate between the extremities of the range comprised by a bridge scale are:

$$B^2 = PQ,^1 \tag{8}$$

$$e = \frac{P(l - s_1) - BS_1}{B - P}. \tag{9}$$

In expressing these equations it is assumed for simplification that S_1 and S_2 are symmetrically located on the bridge scale so that $S_1 + S_2 = l$ in all cases.

A single example will illustrate the magnitude of the deviations between the two curves, and, in order to bring this out clearly it has been necessary to carry out the computation to six figures, which, of course, represents a much higher order of precision than obtains in ordinary work.

TABLE II.

Table of Corrections to Reduce Bridge Scale Readings, t', to Gas Scale Temperatures, t, with a Nickel-resistance Thermometer:

Equation: $\log R = 1.0859391 + 0.00169881t$. $S_1 = 20°$, $S_2 = 80°$, $l = 100°$.

Bridge Scale t'	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
Corrections to gas scale t	+.10	+.04	−.00	−.01	−.01	.00	+.01	+.01	.00	−.04	−.10

Suppose we have fixed upon values of B and e in the equation

$$R' = B\frac{e + t'}{e + l - t'}. \tag{10}$$

Such that the $R't'$ curve intersects the logarithmic curve at two points, PQ. We may now imagine the $R't'$ curve to slide upward or downward along the logarithmic curve, and it will still conform closely to the logarithmic curve. This means that by increasing or diminishing the resistance B we can shift the whole thermometric scale to a higher or lower range of temperatures, while still retaining the value of $e_1 = e_2$ on the bridge, and without changing the deviations of the bridge scale from the temperature scale.

[1] It is a fundamental property of the logarithmic curve that the ratio of any two ordinates, $P \div R_1$ for example, is the same as the ratio, $R_2 \div Q$, of any two other ordinates which are separated by the same horizontal space; that is, when $S_1 = S'$. As a corollary of this proposition, the middle ordinate between two ordinates is the square-root of their product. Therefore, in equation (8), $B = \sqrt{PQ}$ is a point on the logarithmic curve. Consequently, the $R't'$ curve must always intersect the logarithmic curve in the middle point as well as at P and Q. The product PQ is a constant for every pair of ordinates of which B is the middle ordinate.

The data whose examination has called forth the results herein presented are admitted to be open to uncertainty, but it seems that easily available samples of nickel wire show a temperature resistance curve very nearly represented by the logarithmic equation, or, what is nearly the same thing, by the equation (10).

It is therefore worth while to bring out the useful mathematical relations existing between the logarithmic and the bridge scale equations. The matter is of the greatest practical utility, not only in scientific investigations, but in a large field of commercial work demanding a more or less accurate knowledge of moderate temperatures.

In view of the foregoing, we hope those in a position to do so may investigate more fully the variations of resistance of nickel with temperature, and especially the determination of the relation between the composition of the material employed and the character of the resistance curve.

The practical application of all this theory is very simple. The maker of bridges sets up the arrangement shown in Fig. 2. The resistance B must be accurately adjusted to equal the resistance the thermometer will have when its temperature is that represented by the middle point of the bridge scale. The resistances e_1 and e_2 must be accurately *equal*, but the exact value is not of much importance. If e is a little greater or smaller it simply shifts the P and Q points of intersection either nearer to or farther from the extremities of the bridge scale. Having approximated the e coils it remains only to "point" the bridge scale for graduation into equal parts. Put into the bridge any convenient known resistance equal to the thermometer resistance at some known temperature, preferably near the P and Q points of the range. The point at which the bridge balances corrected for the small errors in table II is the particular temperature point of the bridge scale, and nothing more is necessary than to run a scale of equal subdivisions through this point and the middle point of the bridge. The careful man will probably prefer to locate another point of the scale near the upper temperature limit. Any inequalities of resistance of the bridge wire introduce errors, as is well understood, but which can often be neglected or corrected for by calibration if necessary.

ON A RADIAL FLOW POROUS PLUG AND CALORIMETER.

By E. S. Burnett and J. R. Roebuck.

IN any investigation involving the accurate determination of the thermal properties of fluids, the freedom of the experimental apparatus and methods from inherent contributory errors of more than negligible value is of the utmost importance. Where, as is usually the case, the fluid under investigation must pass through several parts of the same or successive pieces of apparatus whose temperatures may differ, the external variants can seldom be under proper control nor can their disturbing influence be sufficiently determined. Undesired and frequently indeterminate interchange of heat by conduction and radiation between the fluid and its surroundings and between the temperature-measuring devices and their surroundings, affect the temperature so measured to an uncertain extent. In the ordinary form of porous plug and fluid calorimeter where the flow is continuous and linear, the most serious errors arise from the complicated radiation and conduction losses unavoidably involved with any temperature gradient between the points at which the temperatures are measured. It is the purpose of this note to describe an experimental arrangement in which these errors are avoided by the use of a radial fluid flow and accompanying radial temperature gradient whose inherent freedom from all detrimental heat interchange is demonstrated in detail below.

For several years past Mr. Burnett has been engaged in an investigation of the Joule-Thompson effect in various gases, and much of the time has been spent in overcoming experimental difficulties of the disturbing nature above indicated. Dr. Roebuck has more recently undertaken some work elsewhere noticed[1] involving apparatus of a similar nature. During one of the many discussions of our respective researches we evolved a scheme of apparatus and procedure which are almost ideal and of wide application.

[1] Phys. Rev., Vol. 30, p. 129.

The fluid under investigation is brought to any desired initial temperature, and maintained there by passing through a coil immersed in a bath controlled by a suitable thermostat. After passing through the coil its temperature is measured by a thermometer immersed in the fluid; under these conditions the thermometer, fluid and walls being continuously at the same temperature, radiation and conduction errors are avoided.

The next part of the apparatus which may be described as the "radial flow" portion constitutes the essential improvement. It is situated in the bath with adequate thermal insulation therefrom. Figs. 1 and 2 represent diagrammatically the principal features of

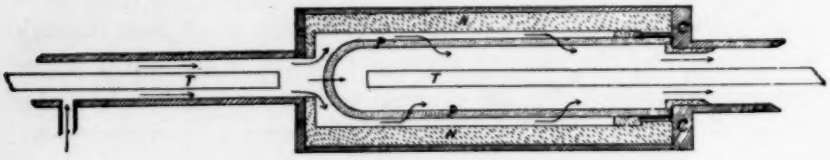

Fig. 1.

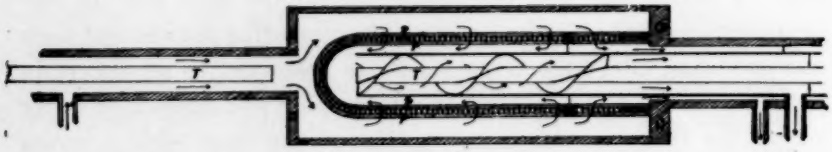

Fig. 2.

C, metal container; *N*, insulating material; *P*, porous plugs; *I*, thermometers.

two cases. In the porous plug form this consists of a round-ended porous tube of suitable non-conducting material (*e. g.*, porcelain). In calorimetry it consists of two concentric opaque tubes offering however practically no resistance to the flow of the fluid which is electrically heated as it crosses the space between them. The fluid is let toward the outer surface of these non-conducting tubes, flows radially through them, gathers within, and is led away through a passage preferably insulated from the bath. The second temperature is measured within the porous tube by a thermometer whose stem is thus protected by the outflowing fluid.

Two cases are to be distinguished, first when the fluid passes through the porous partition with a rise, and second with a fall of temperature. In the first case the conduction of heat by the porous

walls is opposed to the flow of fluid and only very small flows would be necessary to completely offset this minute conduction; as a consequence both outer and inner surfaces of the plug would be exactly at the temperature of the fluid and thus both radiation and conduction losses would be entirely avoided. In the second case the conduction takes place in the same direction as the flow, but conduction from the outside can only carry heat from the fluid entering to the fluid leaving the walls and therefore cannot influence the thermometer readings. Its total effect will be to shift slightly the temperature of the plug surfaces from that of the passing fluid, and so might give rise to appreciable radiation errors. The minute conductivity of porous material and the intimate contact of the fluid with the wall render this error negligible in most cases. Insulation of the porous tube from its container in the bath by suitable non-conducting material, confining the fluid flow to the region adjacent to the porous wall, will minimize any possible radiation loss from the plug, or other interchange of heat after its initial temperature has been measured.

In both cases the support of the porous tube should be arranged to prevent radiation to or from the second thermometer. When used as a porous plug the effect of axial conduction along the porous wall from its support is without influence on the second thermometer reading because the fluid which passes close to the support does not come in contact with the bulb of the thermometer. When used as a calorimeter the fluid must be mixed before passing the thermometer. The end effects near the tube support can be eliminated by a guard ring arrangement. This can be accomplished by respective division of the heat supply and the fluid flow as it passes through the porous walls and leading the divided flows away independently.

Either apparatus may be so designed as to be compact, self-contained, yet flexible, and adapted to a wide range of temperature and pressure without departing from the essential features of merit.

PHYSICS LABORATORY,
UNIVERSITY OF WISCONSIN, December 7, 1909.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE FIFTY-FIRST MEETING.

A REGULAR meeting of the Physical Society was held in the Physical Laboratory of the College of the City of New York on Saturday, March 5, 1910, President Henry Crew presiding. The following papers were presented:

Presidential Address: Physics and Metaphysics. HENRY CREW.

1. On the Thermodynamics of Black Radiation. PAUL SAUREL.

2. The Recovery of Selenium from X-Ray Excitation. LOUISE S. MCDOWELL.

3. The Clock as a Measure of Time and of Space. G. N. LEWIS.

4. The Second Law of Thermodynamics. W. S. FRANKLIN.

5. Heat Transfer due to Steam Condensation. S. LEROY BROWN.

6. Experimental Demonstration of Vortex Rings in Fluids. E. F. NORTHRUP.

7. The Heat Liberated by the Absorption of Electrons by Metals. O. W. RICHARDSON and H. L. COOKE.

8. Hydrodynamical Theory of an Electron in an Elastic Medium. J. G. COFFIN.

9. On Wien's Displacement Law. PAUL SAUREL.

10. Mechanical Model of an Electron. J. G. COFFIN.

11. A Commerical Type of Ammeter for the Precise Measurement of Alternating Currents Greater than 500 Amperes. E. F. NORTHRUP.

TEMPERATURE COEFFICIENTS OF ELECTRICAL RESISTANCE.[1]

BY ALBERT A. SOMERVILLE.

THE range of temperature through which the work extends is from 0° C. to about 1060° C. — limits well within the range of the platinum resistance thermometer. Callendar's[2] temperature resist-

[1] Abstract of a paper presented at the Boston meeting of the Physical Society.

[2] Phil. Trans., Vol. 178.

ance curve for platinum is taken as a standard and temperatures are measured in terms of this.

The heating device consists of an electrical resistance furnace, made by wrapping nichrome ribbon wire around a porcelain tube having an inner diameter of 3 cm. and walls 1 cm. thick. This is enclosed in a second porcelain tube and a coating of asbestos about 6 cm. thick. The total length of the furnace is 50 cm. Its resistance when cold is 5 ohms. When connected to a 55 volt circuit a temperature of almost 1200° C. is attained in an hour. It can be held constant at any temperature by varying the current. Usually about three hours' time is taken to run through a temperature change of 1000° C.

The platinum thermometer is calibrated at the temperatures of melting ice, steam and the melting points of copper in air and in nitrogen. Frequently when making runs the copper lead wires are melted off in order to verify the temperature reading at that point.

The thermometer is connected with a Callendar automatic temperature recorder, consisting essentially of a slide wire bridge, the galvanometer when deflected closing the circuit through electromagnets which draw the sliding contact along to a new balance. The chronograph attachment draws a time-resistance curve from which may be read a time-temperature curve. By placing a resistance in series with the dummy leads the instrument may be brought within the range of the temperature to be measured and by putting a resistance in parallel with the slide wire the sensibility may be varied as desired.

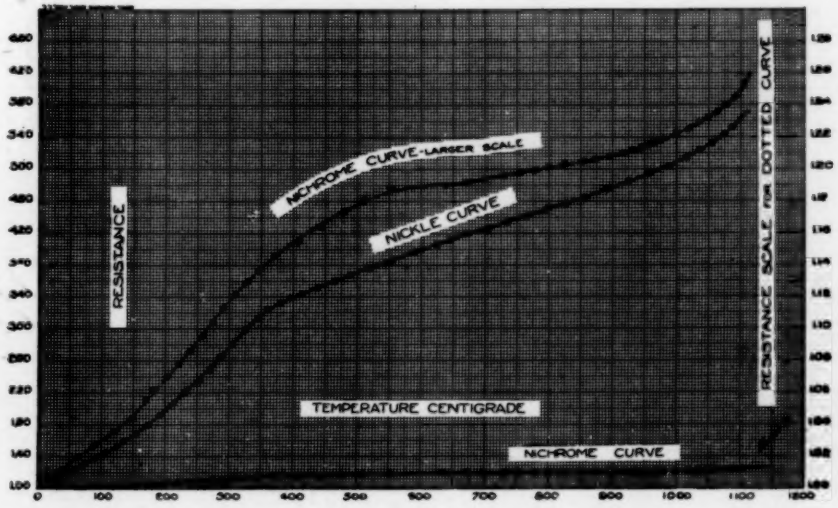

Fig 1.

Two materials tested were nickel and nichrome, the latter being an alloy made by Driver Harris Wire Company, Harrison, N. J., which in the form of a ribbon is well adapted to furnace manufacture. It stands a temperature of not less than 1200° C. and does not oxidize readily.

Both of these materials were made up in the form of resistance thermometers, that being a convenient form in which to test them. The resistance was measured by a dial bridge to the fourth decimal place. The temperatures were indicated by the platinum thermometer in connection with the Callendar recorder. The temperature-resistance curves for nickel and nichrome are similar in general form and that a peculiar one, but the coefficient of the former, is about twenty times that of the latter. These wires could be drawn and sufficient lengths used in a compact form so as to measure half an ohm at 0° C.

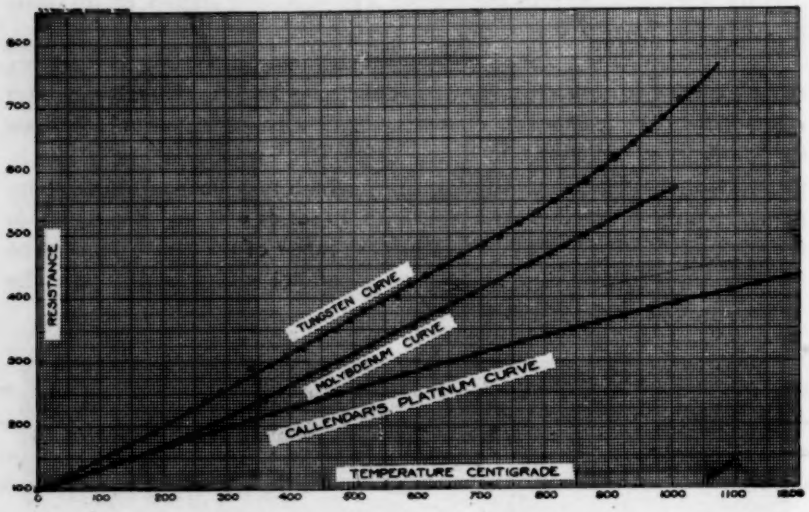

Fig. 2.

Other specimens tested were tungsten and molybdenum, furnished by General Electric Company, Harrison, N. J. These were in the form of hairpin filaments about .3 mm. in diameter and 20 cm. in length. These oxidize quickly at a rather low temperature. Copper or platinum lead wires were fused onto these filaments, using an arc in an atmosphere of hydrogen. They must also be kept in a non-oxidizing atmosphere while in the furnace. This is accomplished by passing a small stream of nitrogen through the quartz containing tube while it is being heated.

It is expected to extend the work to other materials.

PHYSICAL LABORATORY,
CORNELL UNIVERSITY.